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OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NIAGARA FALLS CONVENTION,

JUNE 29 TO JULY 3, 1903.

PAPERS AND DISCUSSIONS, JUNE 29, JUNE 30 AND JULY 1, 1903.

FOR TABLE OF CONTENTS SEE FIRST PAGE.

Papers and Discussions of July 2d and July 3d will appear in the October Number.

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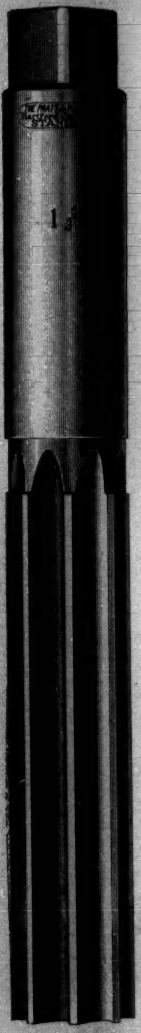

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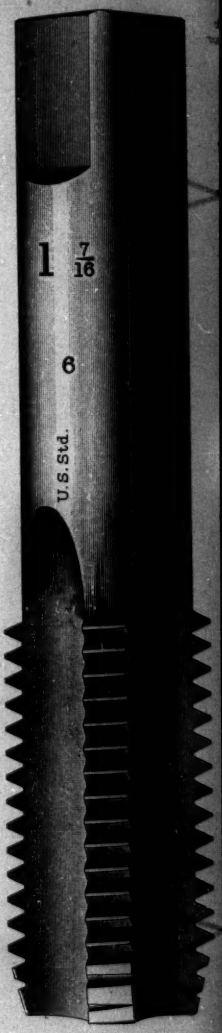

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...e Niagara Falls Convention from June 29 to July 1.
...he papers and discussions of July 2 and 3, the last days
...f the meeting, will appear in the next issue. The present
...olume runs into some 460 pages, and contains a very large
...ercentage of the papers read at the convention, together
...ith the discussions thereon, as well as the independent
...iscussions on engineering topics. The whole forms a ver...
...omplete and exhaustive book of reference. E.E. ...S

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XX. AUGUST AND SEPTEMBER, 1903 No. 7

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

TWENTIETH ANNUAL CONVENTION.

NIAGARA FALLS, N. Y., June 29–July 3, 1903.

MONDAY—MORNING SESSION.

PRESIDENT CHARLES F. SCOTT called the convention to order in the auditorium of the Natural Food Company at 10:30 A. M.

PRESIDENT SCOTT:—During the past year, when it became necessary to determine the place at which to hold this convention, we had cordial invitations from a number of cities, but for one reason or another there seemed not to be sufficient and satisfactory reason for accepting any of them. The chairman of our committee asked me what to do. I said: there is one place in America which seems to me to be pre-eminently the convention city; it is central, it has unsurpassed natural attractions; it is accustomed to holding and receiving large numbers of people and important conventions, and, more than that, it is a place where we may go and be independent; while we would be glad to receive such courtesies as might be freely extended we would feel that we were not imposing ourselves upon any of our local membership.

I take pleasure this morning in presenting to you the mayor of this famous city, a city far-famed throughout this whole world not only for its unexcelled natural surroundings, but also for its pre-eminence as an electrical city—Mayor Hancock.

MAYOR HANCOCK:—Mr. President and gentlemen.—Since I have been mayor of this city I have had the pleasure of offering the glad hand of welcome to many conventions. I even tried a short time ago to welcome a distinguished French gentleman who was visiting here, but as I couldn't talk French and he couldn't understand English, we didn't hit it off very well. But I want to say that I have never had the honor of presenting the freedom of the city and the whole bunch of keys to a more distinguished convention than this one before me. While I have been growing up to my present magnificent proportions many changes have been taking place in this town. When I was a boy this place consisted of two villages containing seven or eight thousand people, Niagara Falls and Suspension Bridge. Every year about

May 1, Niagara Falls woke up. Some of us took down the shutters, dusted off the feather fans and the Indian bead work and the pieces of table rock brought over from England and prepared to offer them for sale to the gentle stranger at reasonable prices. Others of us shoved out the family hack, shook the kinks out of the horses' legs, drove down to the hotels and depots and offered that same gentle stranger a ride around the Falls for five cents, expecting, of course, to get all the traffic would bear when that lovely ride was over.

Some eighteen or twenty years ago Mr. Gaskill and Mr. Evershed, the former a flour miller and the latter an engineer of Rochester, sprung the idea of harnessing the Niagara. They started out to raise the wind, but had the wrong kind of bellows, I guess. A little later Mr. W. B. Rankine and his friends took up the project, the result being that to-day Niagara Falls is a prosperous city of 25,000 people, with many large factories, and its development in the electrical line, I think, has only just begun.

I trust, gentlemen, you may have a pleasant week and enjoy yourselves. I thank you.

PRESIDENT SCOTT:—In the arrangements for a meeting of this kind there are a great many preliminary labors usually on the part of painstaking men who are not much in evidence. The man who has had this convention at heart through the year, who made the preliminary arrangements and who has looked after the papers for this meeting, is Dr. Sheldon, the chairman of the Papers Committee, to whom a great deal of credit is due. A few months ago, when it became necessary to make the specific arrangements, Dr. Sever was called to the chairmanship of the General Committee to have in charge the arrangements for this convention. As chairman of the local committee, Mr. H. W. Buck was selected. The success which may come to this meeting is largely due to the efforts of these three men, seconded by the members of their committees.

I announced the names of three gentlemen who have been prominent in arranging for this convention. There is another that I omitted. We may omit him because we take him for granted. He is active all the time—the Secretary.

President Scott then read his annual address as follows:

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

PRESIDENT'S ADDRESS—JUNE 29, 1903.

CHAS. F. SCOTT.

The engineer is defined as "one skilled in the application of the materials and forces of nature to the use of man." Once he dealt almost wholly with materials—some do so still, arranging brick and stone and iron to form bridges or buildings which stand inert. Others combine materials and forces. But the electrical engineer deals with forces, with energy in its moving, kinetic form. His unit is not one of length or mass or volume or strength—it is the kilowatt, a unit of activity. If the flow of energy cease, the electrical system is inert, as useless as the body when life is gone. He energizes and vitalizes the systems constructed by engineers of many kinds. Hence the phenomenal rate of electrical extension—it is not a new thing separate and apart from other things, it enters into them, it operates, it awakens, unites, transforms.

Among the various branches of engineering many are of old standing and have been developed during many years; the greater part of what is standard to-day may be found in the text books and the treatises of a generation ago. On the other hand, the second edition of Kapp's "Electric Transmission of Energy" which is less than fourteen years old contains no reference—other than a sentence in the preface—to the commercial use of alternating current, although it has already become well-nigh universal. If one were about to install a long distance transmission plant he could call hydraulic engineers as advisers, who have had many years of experience. But he would find that

electrical engineers have had scarcely any experience with the high voltages which are now being introduced. In fact the plants which have been operating at 40,000 volts for more than two years may be counted upon the fingers of one hand or even upon the thumb.

The newness of electrical work is shown also in our large cities which depend for their street railways, for their light and for their power upon apparatus in central stations and upon methods of transmission which were unknown a dozen years ago.

The electrical reports in the U. S. Census show that the mean rate of increase in electrical activity as measured by the capital invested is 20 per cent. each year—it doubles in four years.

Technical schools, electrical courses and laboratories have increased wonderfully, but their output of young engineers does not supply the growing demand.

Note how electrical and other interests are interdependent. The underground railway systems in New York City require the work of almost every branch of engineering. The purpose of the whole is the operation of trains. Everything contributes to that end. The operation is by electricity. So also does every department of the system come into relation with the electrical engineer; the design of the power house, of the locomotives or motor cars, of the tunnel, of the track, of the stations, the arrangements for handling passengers—all are related in some way to the electrical system. And naturally so—they all are the passive elements contributing to the one active end, train operation, and electricity is the immediate active element by which trains are operated. Hence, in general, all else is adapted and contributes to the electrical system and must harmonize with it. Hence the electrical engineer is the central engineer, he more than any other comes in contact with all; he more than any other needs to know something of all other departments and professions.

Just as the workmen in a factory depend upon tools and motors and transmission circuits and buildings in order to do their work, so also does modern society depend, for that something which we call commercial and social life, upon mills and factories, upon facilities for travel and communication and upon its bridges and its buildings, its engines and dynamos—all, the results of engineering work. We know all this, we know that the new attitude toward nature beginning with the achievements of Copernicus and Galileo and Newton marked the beginning of new methods of thought and of action. We know that mechanical

power by means of the steamship and the railway train has had the most profound effect upon modern life in every particular—commercial, industrial, social, political. We recognize the new impetus which has been imparted by electricity during the past score of years. We know all these as physical facts and we see their immediate effects. But we are so surrounded by them and they are so close upon us at every hand and we have become so accustomed to them that I question whether any of us appreciate and realize their full significance. The immediate effects are readily seen. It is the indirect but far-reaching influence of the new agencies which is not so easy to discover.

In this new era the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS represents the profession which is youngest in years yet foremost in activity. To meet the present demands of this new era, to prepare for an expanding future, we may well ask, What should our INSTITUTE be? What should it do? Shall we adopt the methods of the old time learned society? Shall we imitate the ways of societies or professions whose methods are established and whose rate of change is slow? Shall we reserve preferment for those with hoary locks or well-rounded years of experience?

Not only the activity of our profession but the spirit of the times demands something different. We cannot stand aloof, we cannot be exclusive—we must recognize that we are in a new era with its unprecedented rate of progress. We cannot wait till men develop through many years of experience, for they are needed quickly—how then can we increase the efficiency of their training and accelerate their development? We have no long record of achievement and experience to guide; we must execute and operate in a dozen places what has scarcely had time to demonstrate its success in its first installation—how then can we increase the efficiency of our work by extending the knowledge of that which has been done and by crystalizing from present practice that which should be made standard?

A year ago when your votes imposed the responsibilities of the presidency upon me, it seemed that while the preceding year had fixed a high standard for our monthly meetings in New York, we should develop next some method by which distant members might take much more active part in our work. I took up the conditions confronting me as a definite problem. I studied it and discussed it with others; it grew and new phases appeared. The problem as it presented itself to my mind together with

certain specific ways for advancing our interests were set forth in an address upon " Proposed Developments of the INSTITUTE " which I read at the beginning of the year. I may add now that the more deeply I have become involved in the affairs of the INSTITUTE the more interested have I become and the greater have its possibilities appeared.

In that address of last September several specific ways were proposed by which the work of the INSTITUTE might be advanced during the year. Let us review them briefly, noting their bearing upon the future.

(1) " The membership should be increased."

My own convictions were expressed during the year in the following words: " We have failed to catch the spirit of the times and the keynote of electrical progress if we do not realize that we must expand and broaden and progress as well as maintain high standards of excellence. Full membership should be exclusive, associate membership should be inclusive."

Our membership list on September 15, 1902, included 1630 names. Since that time nearly 1000 applicants have been elected as Associates. Who are the men who have come among us? What is their age, what has been their training, what is their present position?

The new men range in age from 19 to 65. The ages of those who have been elected are given in the following table:

Over 50 years	2%
45 to 50 years	2%
40 to 45 years	6%
35 to 40 years	10%
30 to 35 years	24%
25 to 30 years	34%
20 to 25 years	21%
Under 20 years	1%

Approximately 60 per cent. are between 25 and 35 years of age and are presumably young men who are getting under substantial headway in life and are in their accelerating period.

Forty-four per cent. of these men are graduates of schools of recognized standing. Of the graduates 45 per cent. graduated within the past 5 years (not including 1903), and 77 per cent. within the past 10 years. Cornell University leads the list with 12 per cent. of the graduates; the Massachusetts Institute of Technology is second with 8 per cent. Columbia, Purdue, Ohio State, Princeton, Worcester Polytechnic Institute, Lehigh,

University of Michigan and the University of Wisconsin follow next and there are substantial numbers from McGill, Stevens Institute, University of Pennsylvania, University of Illinois, University of Minnesota, Pennsylvania State College, University of Nebraska, University of California, Harvard, Yale, and Rose Polytechnic Institute. In addition there are graduates from numerous additional institutions, as well as many others who have not taken degrees.

The position and occupation of the new members is difficult to classify definitely, but a general summary shows the following:

Electrical engineers with manufacturing companies	30%
Electrical engineers with operating companies	25%
Managers and superintendents, duties presumably executive rather than technical	16%
Consulting engineers	10%
Electrical engineers with mills, mining plants and the like	6%
Students	6%
Professors and instructors	4%
Mechanical and electrical draftsmen	3%

I think we may congratulate ourselves that our additions are truly representative of the electrical engineers of America, including not only those advanced in the profession, but young men of promise—the engineers of the future. An addition of 60 per cent. to our numbers in a single year principally of men who are entering active engineering work and who have been attracted to the INSTITUTE because they believed that it was well worth while to join, means much to the INSTITUTE, it means much to the men and it means much to the electrical engineering profession.

Other plans proposed at the beginning of the year were that:

(2) "Papers and discussions should be contributed from a larger proportion of the membership."

(3) "Local meetings of the INSTITUTE in various cities will broaden the interest of its work and generally extend its benefits."

(4) "Universities and technical schools with electrical engineering departments may organize local meetings of the INSTITUTE."

These three lines of activity have developed most satisfactorily and are closely related to each other. General plans were presented for the formation of local branches and such branches have been formed among members in a number of leading cities;

also in many of the principle technical schools and universities. In some cases local members and students unite. The methods have been simple: there is a minimum of organization and formality; the primary purpose is to bring electrical men together, to awaken interest, to consider and discuss important engineering topics. At the beginning of the year definite subjects were assigned for each month for the meetings in New York. Usually several papers were secured from experts upon each subject. Printed copies of the papers, together with the stenographer's report of the New York discussion have been sent promptly to the secretaries of the local branches. As the branches have usually held their meetings subsequent to the meeting in New York, they have had the advantage over the first meeting in having the discussion as well as the papers. This material is presented in suitable form by the members of the local branches and the discussion is continued. Such material as is new and valuable is reported to the Secretary for publication in the transactions. By this means the latest phases of electrical engineering work are presented and discussed not in one meeting only but in more than a score.

Those who have taken up the local work usually report that the interest, the activity and the attendance surpass expectations. In nine cities in which local branches have been formed the total membership has practically doubled. The attendance is not limited to members, as others are welcome. A number of professors have spoken of the interest taken by students and the avidity with which they enter into the work. One professor recently remarked to me that the INSTITUTE papers were giving him a new insight into present electrical engineering and such papers as those upon Central Station Practice made him realize how far practical engineers were in advance of the lecture room and the laboratory.

The element of greatest importance in this extension of our work is to my mind not so much the mere technical knowledge which it may diffuse but the broader aspects of up-to-date problems which it presents and the sentiment of unity and coöperation among electrical men. Electrical engineers have not the advantage of long time acquaintance, but in this plan we have an effective means of bringing them together, of uniting them in a common interest and of directing the studies and the work of young men along definite and effective lines.

At the beginning of the year it was indicated further that:

(5) " The collection of engineering data and the establishment of standard practice in electrical engineering is one of the important functions of the INSTITUTE."

The present years are formative years. Electrical engineering is crystalizing. In addition to our Committee on Standardization two new committees have been formed, one on High-Tension Transmission, the other on Engineering Data. The Transmission Committee is composed of engineers of recognized standing. A consulting engineer is the chairman, and representatives from several large manufacturing companies and a western university complete the committee. This committee is collecting specific data with respect to present practice in high-tension transmission and will formulate this data for the use of electrical engineers. It has further prepared a number of short papers as introductions to discussions upon a number of important branches of transmission which is calling forth the opinions and experience of engineers at large.

The Committee on Engineering Data is composed of men of high standing, under the direction of the Electrical Engineer of the Niagara Falls Power Company. It has been appointed for collecting and publishing electrical engineering data upon new and special subjects which are evolving daily throughout the country in the practice of the engineering profession. There is much important data which has not found its way into text books and hand books and about which little is generally known. Such data, if allowed to follow existing channels, either never reach the public, or only after a long period. The first subject to be taken up for investigation is insulated electrical conductors. Under this general subject is included the heating of cables of various character under different conditions, the life of cable insulations, the methods of ventilation in conduits, the effects of short circuit, and general data bearing upon the operation of cable systems.

I count such work as has been undertaken by these committees as of the highest importance to the INSTITUTE and its members, for it deals with matters vital to substantial electrical progress. They are the means of carrying out one of the highest functions of the INSTITUTE in bringing together the diversified achievements of many workers which in the aggregate constitute a single total of accomplishment which we designate as progress. They bring definite and systematic results out of what is otherwise indefinite and chaotic. Thus they lay the foundation for advancement.

As a further department of our work it was stated at the beginning of the year that:

(6) "Our library merits a cordial support." The generous contributions of members have been continued during the year by substantial additions to our valuable collection, not only in contributions of present volumes but in endowment provision for the continuation of sets which have been presented. Plans are now under consideration for giving our own TRANSACTIONS —a panoramic history of American Electrical Engineering— greater value by preparing a general index to be issued both in pamphlet form and also on cards, which may be distributed alphabetically through the card catalogues of public and private libraries.

The crowning event of the year was in a measure anticipated by these sentences of last September:

(7) "Permanent quarters for the INSTITUTE should be an object of plans and anticipations. * * * Personal acquaintance and social intercourse are influential factors in unity of sentiment and of action."

The story of our Library Dinner with its distinguished guest who spoke in happy mood of American engineers and of coöperation among them and of "institutions like this of the Electrical Engineers which do so much" is already familar to you, as well as the events of the following day when he called to his house two of our members to talk further of what an engineering building should be and of plans for its realization. I count as the most memorable privilege of the present year the opportunity given me of sitting next to Mr. Carnegie on the evening of our Library Dinner and the hour in his own library on the following afternoon. At the dinner he was in the best of spirits, alert, and ever interesting as conversation shifted easily from one topic to another. The talk was pleasant and appropriate to the hour but never trivial. One topic after another came up, but it was the more serious, the more definite, the substantial idea which he brought out before turning to something else. The happy response to his toast was almost throughout a repetition of the ideas and the sentiments which he had expressed in the conversation of the preceding hour.

In discussing at his house the next day the project of an engineering building he impressed me as seeking the way by which he could realize an ideal. He was not very familiar with the organization of the several engineering societies, he knew

little of their methods and of their financial means and their facilities. But he saw a need, not merely the physical need of accommodations, but the higher need of elevating and developing engineering and engineers. He used about these words: "Yes; engineers need to get together, they need to get acquainted and to meet socially. You can provide for that, can you not?" In his address as President of the Iron and Steel Institute since that time he has discussed methods of industrial organization, particularly the relations between men, and he has emphasized the advantages of a general partnership and common coöperation. When, a few days after our first conversation, estimates and a general scheme of procedure were presented, Mr. Carnegie did not care to go into the details of method. He seemed to have confidence that engineering organizations could develop their plans in the ways which would be most efficient. He set no restrictions. The great Gift to Engineering is presented in a single sentence shorter even than the superscription of the letter which proffers a million dollars. Four of the organizations (the fifth has not yet taken final action) which were designated in his letter have without hesitation formally accepted the administering of this generous gift to engineering and their representatives are now actively developing plans. These plans look forward to the realization of an ideal long cherished by some of the foremost and far-seeing engineers of the country, an ideal in harmony with the new era in engineering and with the trend of American development, an ideal which brings within its scope the advancement of the engineer and of his profession both within itself and in its outward relations. In short, an ideal the realization of which will strengthen modern engineering—the very basis of national prosperity and progress—and will exert influences which are beyond our power to discern.

The remaining specific way mentioned at the beginning of the year for advancing the interests of the INSTITUTE was:

(8) "Coöperation with similar institutions in other countries."

Our relations with the Institution of Electrical Engineers of Great Britain in particular are most cordial and beneficial, and we are planning to have its members with us at the time of the Engineering Congresses to be held at the St. Louis Exposition next year. But the idea of coöperation has had its development along domestic rather than foreign lines. It is not worth while here to recount the advantages of coöperation. We recognize it as the modern method. The possibilities which may come

through coöperation among engineers and in engineering work are hardly less than those which are recognized in industrial, commercial, financial and social affairs. The founding of the John Fritz medal, and the gift of a Union Building are magnificent examples.

In the interrelations between societies, care must be taken that individuality and freedom for individual development are unrestricted, and that the points of contact and common endeavor are only those in which the most efficient results can be obtained through coöperation. I think all will agree that just as electricity has been pre-eminently a unifying element in modern affairs, so also the electrical engineer should be a unifying element in the engineering profession and that there should be in particular a coöperation among electrical organizations. Let us develop the ideal and then realize it as best we may, step by step, in the future.

To present definitely a general scheme I will give the substance of a suggestion which I presented to our Committee on Affiliated Societies which now has the general subject under its consideration.

First.—A plan should be outlined providing for special departments or sections of the INSTITUTE for such lines of electrical work as may demand greater attention than can be given by the INSTITUTE as a whole and which can be more efficiently conducted in this manner than by the formation of new specialized societies.

Secondly.—Affiliation or coöperation is desirable with other electrical associations by which the INSTITUTE may work in harmony along certain lines, such as Standardization, adoption of the National Electric Code, the Collection of Engineering Data and other matters of a general nature. Many associations dealing with specific industries have both commercial and engineering interests. I would make the INSTITUTE the electrical head or center, bringing into a unity the electrical engineering of all these associations, not restricting but broadening their work and making them constituent parts of a great whole.

Thirdly.—There is opportunity for close relations between our local branches and local engineering societies or clubs. In two or three cities the local societies are considering plans of uniting sections of their societies with local branches of the National Societies. Think for a moment of the possibilities in elevating the work and increasing the efficiency of engineering organizations by establishing close ties between local and national

societies—keeping them in close sympathy and coöperation, and bringing them into one great system! The success which has attended our branch organizations augurs well for further extension by similar methods for awakening and stimulating a general interest in engineering subjects.

Fourthly.—There should be coöperation—without affecting their present individuality—between national engineering societies in the nature of a National Engineering Congress for promoting closer relations between the various branches of engineering work and for representing the engineering profession as a whole.

In this summary review of the year's work no mention has been made of less conspicuous though scarcely less important matters—the Committee on Finance, the Committee on Papers, the Editing Committee, the Board of Examiners, the Committee on National Electric Code, the Reception Committee, the Committee on Membership, the coöperation of the INSTITUTE in the establishment of the John Fritz Medal, the plans of the INSTITUTE for the Louisiana Purchase Exposition, the extension of certain privileges to students in electrical engineering upon the payment of a small fee, the plans for receiving graduating theses and according recognition to those of superior excellence. On the Board of Directors and the Committees are earnest active men who have freely contributed time and labor to the advancement of your interests. After all, the element which promises most for our future is the spirit of the men who are leaders in our work and the ready response to their efforts which has come both from our members in carrying out our work and from those who have come in such generous numbers to join with us.

It is difficult to see wherein our work can be materially reduced without serious loss. It is easy to see how it may be expanded. I emphasize particularly the establishing of permanent committees to be continued from year to year to carry on lines of work such as the committees on standardization, on transmission, and on engineering data. The value of the results is unquestioned, but the amount of work necessary is not so readily appreciated. We must depend for our best work upon the men who are busiest and who are in a way least able to give it. We must efficiently utilize small contributions of endeavor and assistance from many men. This requires organization and direction, these men should have the fullest assistance from others who are paid to carry out their directions and to care for details.

Our expenses are within our income simply because we have been watchful, restricting expenditure at every turn. In order to expand and to carry out the lines of work which are most valuable to ourselves as individuals and for the substantial promotion of electrical engineering and of electrical industries, we need money.

In the Union Building for the Engineering Societies, it devolves upon the societies to provide the land upon which the Carnegie gift is to be placed. To provide for the INSTITUTE in this matter, a committee has undertaken the raising by subscription of a fund for this purpose. This magnificent supplement to what Mr. Carnegie is doing will give the INSTITUTE rent free its building for general meetings, for library, for offices, reading and reception rooms and the like. This will enable us to devote to technical purposes the funds which would otherwise be required for rent, which are considerable now, and would be greater in the future.

We anticipate substantial contributions from those who have reaped a rich reward from the applications of electricity. Their wealth has come in no small degree from the work of electrical engineers. Whatever the INSTITUTE may do in raising the standards and increasing the effectiveness of electrical engineering brings rich returns to those men and particularly to those companies commercially interested in electrical pursuits. The farmer saves from his surplus the best seeds for the coming season—should not some of the wealth which engineering effort has produced be returned to train men and to develop methods for the future? Is not the wholesome recognition of the engineering profession by Mr. Carnegie coupled with his generous gift but the beginning of a new attitude toward engineering and of better things to come? Engineering researches and investigations and tests requiring large sums of money should be undertaken. It is not too much to hope that if we use well the talent which has been given us more may be entrusted to our keeping.

But building and library, professional papers and technical data are only the facilities, the means, the tools, for the men who are to use them. We must develop men, more effective men. Let us maintain high standards of excellence, of professional attainment and of intgerity. This does not require that we be too exclusive, holding ourselves aloof and apart. In religion the ideal is no longer the monk in the cloistered cell, it is activity in daily life. Electrical engineering is in contact with many interests, let electrical engineers be in touch with many men. In

one sense engineering and commercialism are widely apart. Yet there is a commercial side to engineering, not mere selling, but the adaptation of engineering work to definite industrial and commercial conditions in such manner as to bring the best results. In our papers we do not discard subjects which are of engineering interest and value, simply because they may be of financial importance to some one. It is not our function to treat simply of the things which are of no value to anybody. Yet our criterion is not commercial, but engineering; practical common sense, not sentiment, must prevail in our relations to things and to man. The engineer is not merely the man in the closet surrounded by slide rules and tables. Electrical enterprises depend upon manufacturers, industrial captains and financial managers—upon those who construct and apply and use and direct the results of engineering work. Engineers should know these men and work in harmony with them. The plan for the new Union Building—the Capitol of American Engineering—not only brings engineers of different professions together but it recognizes broader relations, as the engineering societies will be adjacent to a social club " composed of engineers and others who may be interested in or connected with the engineering profession."

We are in an engineering age, an electrical age, with its physical commercial, industrial and social changes, with its new conditions, new opportunities and new responsibilities. And these are the beginnings of yet greater things to come. Let us be awake to the times and in touch with modern methods. Let us make the work, the methods and the ideals of our INSTITUTE in full harmony with that profession which deals with kinetic energy and whose units of measure are the units of activity and whose mission it is to awaken, to energize, to unite, to transform, to operate, to make effective.

PRESIDENT SCOTT:—I would like to make a little re-arrangement of the program, taking up Dr. Franklin's paper next.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 29th, 1903.

ENERGY TRANSFORMATIONS IN THE SYNCHRONOUS CONVERTER

BY WM. S. FRANKLIN.

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1. Introduction.

The engineer ordinarily approaches the study of the synchronous converter with ready made knowledge of the direct current dynamo and of the alternating current dynamo. The result is that the action of the synchronous converter is usually described in terms of the activities of the synchronous alternating current motor and the direct current generator, and the

theory of the synchronous converter is usually developed in terms of those notions which apply primarily to the synchronous alternating current motor on the one hand, and to the direct current generator on the other. As a matter of fact, the *external electrical relations* of the synchronous converter may be completely represented by this method of attack. When, however, the synchronous converter itself—its *internal activities*, as it were—is the object of study, the notions of the synchronous alternating current motor and of the direct current generator do not suffice. There are certain elements of behavior of the synchronous converter which are foreign both to the synchronous alternating current motor and to the direct current generator; to examine into these elements we must attend to the actual physical activities of the synchronous converter without regard to the mathematical analysis of these activities into their more or less fictitious and unreal component parts, namely: synchronous motor activities and direct current generator activities. I give in a subsequent section of this paper a statement of the criterion which enables one to judge of the physical reality or unreality of the component parts into which a physical aggregate is resolved by mathematical analysis, and it suffices here to state that this criterion shows the physical unreality of synchronous motor activity and direct current generator activity as component parts of the activity of the synchronous converter.

2. The Synchronous Converter Compared with the Auto-Transformer. Statement of Object of this Paper.

Let b Fig. 1 represent one of the d.c. brushes of a two-ring converter. Let this brush be chosen as the zero or reference point of potential, and let a represent the other d.c. brush. Let r be the position of the a.c. tap at a given instant. This tap r is at a potential which is between the potentials of b and a. Let i be the instantaneous value of the alternating current entering at r. A portion, A, of this current i flows up hill, as it were, from r to a, receiving energy because of assistance due to the induced electromotive forces in the windings between r and a. Another portion, B, of the current i flows down hill from r to b, giving up energy because it is opposed by induced electromotive forces in the windings between r and b.

Let b, Fig. 2, represent one of the service mains to which alternating current is supplied by an autotransformer. Let this main be chosen as the zero or reference point of potential, and let a represent the other service main. Let r and r' be the two supply mains. The main r is at a given instant at a potential which is between the potentials of b and a, and the current i, which enters at r at the given instant divides into two parts, A and B. The portion A flows up hill, as it were, to a, receiving energy because of assistance due to the induced electromotive forces in the windings between r and a. The other portion, B, flows down hill, from r to b, giving up energy because it is opposed by induced electromotive forces in the windings between r and b.

The energy received by the current A as it is boosted up from r to a is in general equal to the energy which is delivered by the current B which flows down from r to b.

The energy received by the current A as it is boosted up from r to a is equal to the energy which is delivered by the current B which flows down from r to b.

In the autotransformer a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by virtue of the conductive connections between supply mains and service mains through the windings of the transformer. In the synchronous converter, also, a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by virtue of the conductive connections through the armature windings of the converter.

The Synchronous Converter

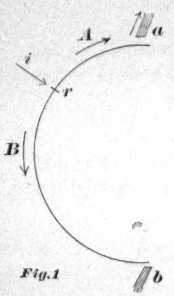

Fig. 1

The Autotransformer

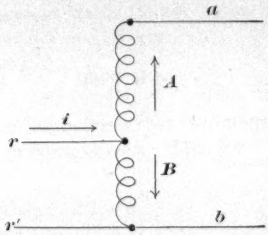

Fig. 2

In the autotransformer a definite portion of the energy which is transferred from the supply mains to the service mains is transferred by being inductively transformed from winding B, Fig. 2, which acts as a primary coil, to winding A, which acts as a secondary coil. In the synchronous converter a definite portion of the energy which is transferred from the supply mains to the service mains, is transferred by being inductively transformed from the portion B, Fig. 1, of the armature winding, which at the given instant acts as a motor, to the portion A of the armature winding, which at the given instant acts as a generator.

The object of this paper is to determine, of the total energy which flows through a synchronous converter, the fractional part which is conductively transferred from supply mains to service mains, and the fractional part which is inductively trans-

formed. In case of the two-ring converter, the inductively transformed energy consists of two distinct parts, namely: (*a*) The energy which is transformed by simultaneous and balanced generator-motor action, and (*b*) The energy which is transformed by successive and unbalanced generator-motor action. These parts will be more fully discussed when we consider the problem of the two-ring converter.

3. The Many-ring Converter.

Fig. 3 represents one side of a two-pole, many-ring converter. E is the electro-motive force between the d.c. brushes a and b, I is the direct current entering at a and leaving at b, i is the current in the armature wires, at a point on the armature which

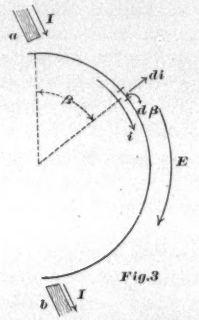

Fig.3

is at angular distance β from brush a, and di is the value of the alternating current flowing out of all the collecting rings connected to commutator bars in the angular element $d\beta$ at the instant that these bars are at angular distance β from brush a. The arrows represent the directions in which the various electro-motive forces and currents are considered as positive.

We shall assume here, as also in the discussion of the two-ring, the three-ring and the four-ring converters, that the converter receives alternating currents at unity power factor, that alternating electro-motive forces and currents are harmonic, and that the losses of energy in the converter are negligible.

Before proceeding to the consideration of energy transformations, it is necessary to determine the distribution of current in

the armature for given direct current output. From the above assumptions, we have:

$$di = -A \cos\beta \,.\, d\beta \tag{1}$$

in which A is an undetermined constant. Integrating this equation we have

$$i = -A \sin\beta + K \tag{2}$$

in which K is another undetermined constant. These constants A and K are determined by the following two conditions: 1st. The generator and motor activities are at each instant balanced in the many-ring converter and 2d, The alternating current input of power is equal to the direct current output of power. In order to formulate these two conditions it is necessary to find an expression for the generator (or motor) action in the element $d\beta$. Let de be the induced electromotive force in the element $d\beta$. Then it is easily shown on the basis of the above assumptions that

$$de = \tfrac{1}{2} E \sin\beta \,.\, d\beta \tag{3}$$

Let dG be the generator action in watts (motor action if negative) in the element $d\beta$. Then $dG = i \,.\, de$, or

$$dG = -\frac{EA.}{2} \sin^2\beta \,.\, d\beta + \frac{EK.}{2} \,.\, \sin\beta \,.\, d\beta \tag{4}$$

The first condition above mentioned requires that the integral of dG from $\beta = 0$ to $\beta = \pi$ shall be equal to zero. That is:

$$\int_0^\pi -A \sin^2\beta \,.\, d\beta + K \sin\beta \,.\, d\beta = 0 \tag{5}$$

which gives

$$\frac{\pi A}{2} - 2K = 0 \tag{6}$$

The alternating current intake of power in the half armature is

$$\tfrac{1}{2} E \int_0^\pi (1 - \cos\beta)\, di$$

and the direct current output of power in the half armature is

$$\tfrac{1}{2} E I$$

and these are equal, so that, using the value of di from equation (1), we have

$$I - \int_0^\pi A \cos^2\beta \,.\, d\beta - A \cos\beta \,.\, d\beta = 0 \tag{7}$$

which gives

$$\frac{I-\pi A}{2}=0 \tag{8}$$

Equations (6) and (8) determine the values of A and K, giving

$$A=\frac{2I}{\pi} \tag{9}$$

$$K=\frac{I}{2} \tag{10}$$

Using these values of A and K in equation (2) we have

$$i=\frac{I}{2}-\frac{2I}{\pi}\sin\beta. \tag{11}$$

It is worthy of note that the problem of the determination of armature currents in a synchronous converter is one which is properly based in every case on energy considerations, as in the above discussion.

We are now prepared to discuss the problem of energy transformations in the many-ring converter. Since the total generator action which is taking place at each instant in the many-ring converter is equal to the total motor action, therefore the inductively transformed power is equal to the total generator action (or to the total motor action). That is: the inductively transformed power, P, is equal to the integral of (4) over those portions of the armature where dG is positive. Now dG is positive where i is positive, since de is everywhere positive, and from equation (11) we find that i is *negative* from $\beta=0$ to $\beta=51°.75$, *positive* from $\beta=51°.75$ to $\beta=128°.25$, and *negative* from $\beta=128°.25$ to $\beta=180°$ Therefore, attending to one-half of the armature and multiplying the result by two, we have:

$$P=EI\int_{\beta=51°.75}^{\beta=128°.25}-\frac{2}{\pi}\sin^2\beta\,.\,d\beta+\tfrac{1}{2}\sin\beta\,.\,d\beta \tag{12}$$

which gives

$$P=0.1153\,EI \tag{13}$$

That is, 11½ per cent. of the energy which flows through a many-ring converter is inductively transformed and 88½ per

cent. is conductively transferred from the alternating current supply mains to the direct current service mains.

REMARK:—The activities of the two-ring, three-ring and four-ring converters are much more complicated than those of the many-ring converter. The wide separation of the alternating current taps in the few-ring converter introduces pulsations in value of current and power in the various windings, as they pass a given point, so that in considering the internal actions of the few-ring converter, everything must be expressed as a function of time; and in the summation of generator and motor actions time integrations are involved.

4. THE TWO-RING CONVERTER.

Fig. 4 represents one side of the armature of a two-pole two-ring converter; r is one of the a.c. taps, a and b are the d.c.

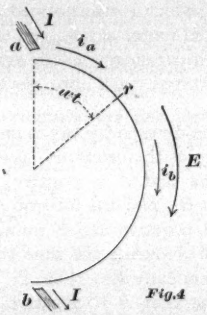

Fig. 4

brushes, E is the electromotive force between d.c. brushes, I is the direct current flowing in at a and out at b, and i_a and i_b are the values of the currents in the armature parts as shown at instant t. The arrows show the directions in which the various electromotive forces and currents are considered as positive.

The algebraic expressions for i_a and i_b are determined fundamentally by the same consideration of energy relations as in case of the many-ring converter. These expressions are:

$$\left.\begin{aligned} i &= \tfrac{1}{2} I + I \cos \omega t \\ i_b &= \tfrac{1}{2} I - I \cos \omega t \end{aligned}\right\} \qquad (14)$$

Furthermore,

$$\left.\begin{aligned}\text{e.m.f. between } a \text{ and } r &= \tfrac{1}{2}E(1-\cos\omega t)\\ \text{e.m.f. between } r \text{ and } b &= \tfrac{1}{2}E(1+\cos\omega t)\end{aligned}\right\} \quad (15)$$

Let A be the generator action (motor action when negative), in watts between a and r; and let B be the generator action (motor action when negative), between r and b. Then

$$A = \tfrac{1}{2}EI(\tfrac{1}{2}+\tfrac{1}{2}\cos\omega t-\cos^2\omega t) \quad (16)$$

$$B = \tfrac{1}{2}EI(\tfrac{1}{2}-\tfrac{1}{2}\cos\omega t-\cos^2\omega t) \quad (17)$$

In case of the two-ring converter, the total generator action does not balance the total motor action at each instant and we must distinguish two parts in the inductively transformed power, namely: the power P which is transformed by simultaneous and balanced generator and motor action, and the power Q, which is first converted into kinetic energy as the armature is accelerated and afterwards converted back into electrical energy as the armature is retarded.

The power $P/2$ (the division by two is on account of our considering one-half only of the armature) is equal to the integral of A during the time that A is positive, B negative, and A numerically less than B; *plus* the integral of B during the time that B is positive, A negative and B numerically less than A; *minus* the integral of A during the time that A is negative, B positive, and A numerically less than B; *minus* the integral of B during the time that B is negative, A positive, and B numerically less than A,—these integrals being extended over half a cycle, and the final result divided by the duration of half a cycle. The value of P so found when divided by EI gives, of the total power which flows through the machine, the fractional part which is inductively transformed without passing through the intermediate stage of kinetic energy.

From equations (16) and (17) we find:

1. Generator action in $a\,r$ is *less* than motor action in $r\,b$ from $\omega t = 0$ to $\omega t = 45°$.

2. Generator action $a\,r$ is greater than motor action $r\,b$ from $\omega t = 45°$ to $\omega t = 60°$.

3. Generator action takes place in both $a\,r$ and $r\,b$ from $\omega t = 60°$ to $\omega t = 120°$.

4. Motor action in $a\,r$ is *less* than generator action in $r\,b$ from $\omega t = 120°$ to $\omega t = 135°$.

5. Motor action in $a\,r$ is *greater* than generator action in $r\,b$ from $\omega t = 135°$ to $\omega t = 180°$.

Therefore,

$$P = \frac{2}{\pi}\int_{0}^{45°} A\,.\,dx + \frac{2}{\pi}\int_{135°}^{180°} B\,.\,dx - \frac{2}{\pi}\int_{120°}^{135°} A\,.\,dx - \frac{2}{\pi}\int_{45°}^{60°} B\,.\,dx \qquad (18)$$

in which x is written for ωt.

The numerical evaluation of the integrals in equation (18) gives:

$$\frac{P}{EI} = 0.09517 \qquad (19)$$

That is: 9½ per cent. of the total energy which flows through a two-ring converter is inductively transformed by simultaneous and balanced generator and motor action.

The power $Q/2$ (division by two is on account of considering one-half only of the armature) is found by taking the integral of $A+B$ during the time that this sum is positive, namely: from $\omega t = 45°$ to $\omega t = 135°$, and dividing the result by the duration of half a cycle. This gives

$$\frac{Q}{EI} = \frac{1}{\pi}\int_{45°}^{135°} (1 - 2\cos_2 x)\,dx = 0.3183 \qquad (20)$$

That is: 31.8 per cent. of the energy which flows through a two-ring converter is inductively transformed by successive and unbalanced generator and motor action.

From the above results, it follows that 58.65 per cent. of the energy which flows through a two-ring converter is transferred from the alternating current supply mains to the direct current service mains by virtue of the conductive connections through the converter armature.

5. The Three-ring Converter.

Fig. 5 shows one side of the armature of a two-pole three-ring converter, r' and r'' are two of the three a.c. taps, a and b are the d.c. brushes, i_a i'' and i_c are the values of the currents in the

armature parts, as shown at instant t, E is the electromotive force between the d.c. brushes. and I is the steady current flowing in at a and out at b. The arrows show the direction in which the various quantities are considered positive.

The algebraic expressions for i_a, i_b and i_c are

$$\left.\begin{aligned} i_a &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t - 150°) \\ i_b &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t - 30°) \\ i_c &= \frac{I}{2} - \frac{4I}{3\sqrt{3}} \cos(\omega t + 90°) \end{aligned}\right\} \qquad (21)$$

For present purposes, we need consider only the generator and motor actions which occur in the three armature parts $a r'$,

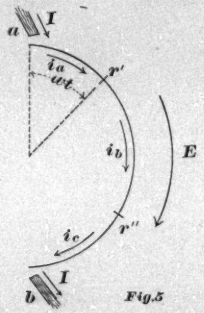

Fig.5

$r'r''$ and $r''b$, during one-third of a cycle, namely, from $\omega t = 0$ to $\omega t = 120°$. The integral of all the generator actions in these armature parts during this third of a cycle divided by the duration of the third of a cycle, gives one-half of the inductively transformed power P.

The electromotive forces involved are as follows:

$$\text{e.m.f. between } a \text{ and } r' = \tfrac{1}{2} E (1 - \cos \omega t) \qquad (22)$$

$$\text{e.m.f. between } r' \text{ and } r'' = \frac{\sqrt{3}\, E}{2} \cos(\omega t - 30°) \qquad (23)$$

This equation is available only from $\omega t = 0$ to $\omega t = 60°$, since at the instant $\omega t = 60°$, r'' coincides with b and after this

instant a portion of the section $r' r''$ is in the half armature which is out of consideration.

$$\text{e.m.f. between } r' \text{ and } b = \tfrac{1}{2} E (1 + \cos \omega t) \qquad (24)$$

This equation is used only during the interval from $\omega t = 60°$ to $\omega t = 120°$.

$$\text{e.m.f. between } r'' \text{ and } b = \tfrac{1}{2} E \left[1 - \cos (\omega t - 60°) \right] \qquad (25)$$

Let A, B', B'' and C be the generator actions (motor actions when negative) in the armature parts $a r'$, $r' r''$, $r' b$ and $r'' b$ respectively at instant t. Then we have:

$$A = \tfrac{1}{2} E (1 - \cos \omega t) \, . \, i_a \qquad (26)$$

$$B' = \frac{\sqrt{3}\, E}{2} . \cos (\omega t - 30°) \, . \, i \qquad (27)$$

$$B'' = \tfrac{1}{2} E (1 + \cos \omega t) \, . \, i_b \qquad (28)$$

$$C = \tfrac{1}{2} E \left[1 - \cos (\omega t - 60°) \right] . \, i_c \qquad (29)$$

Equation (27) applies from $\omega t = 0$ to $\omega t = 60°$, and equation (28) applies from $\omega t = 60°$ to $\omega t = 120°$.

From equations (26) to (29) we find:

A is *positive* from $\omega t = 0$ to $\omega t = 100°.5$
A is *negative* from $\omega t = 100°.5$ to $\omega t = 120°$
B' is *negative* all the time during which it applies
B'' is *negative* from $\omega t = 60°$ to $\omega t = 79°.5$
B'' is *positive* from $\omega t = 79.°5$ to $\omega t = 120°$.
C is *positive* from $\omega t = 0$ to $\omega t = 60°$

Therefore

$$P = \frac{3}{\pi} \int_0^{100°.5} A \, . \, dx + \frac{3}{\pi} \int_{79°.5}^{120°} B'' \, . \, dx + \frac{3}{\pi} \int_0^{60°} C \, . \, dx \qquad (30)$$

Substituting the values of i_a, i_b and i_c from equation (21) in equations (26), (28) and (29), and the resulting values of A, B'' and C in equation (30) and integrating, we find:

$$P = 0.2358\, E I \qquad (31)$$

That is, 23.6 per cent. of the energy which flows through a three-ring converter is inductively transformed by simultaneous

and balanced generator and motor action, and the remainder, 76.4 per cent. is transferred from the supply mains to the service mains by virtue of the conductive connections through the converter armature.

6. The Four-ring Converter.

Fig. 6 shows one side of the armature of a two-pole four-ring converter, r' and r'' are two of the a.c. taps, a and b the d.c. brushes, i_a, i_b and i_c are the values of the currents in the armature parts, as shown at the instant t, E is the electromotive force between the d.c. brushes, and I is the current flowing in at a and

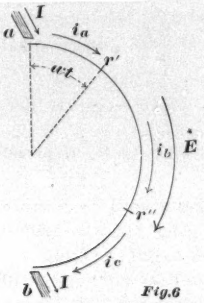

Fig. 6

out at b. The arrows show the direction in which the various quantities are considered as positive.

The algebraic expressions for i_a, i_b and i_c are as follows:

$$\left.\begin{aligned} i_a &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t - 135°) \\ i_b &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t - 45°) \\ i_c &= \frac{I}{2} - \frac{I}{\sqrt{2}} \cdot \cos(\omega t + 45°) \end{aligned}\right\} \quad (32)$$

Furthermore, e.m.f. between a and $r' = \frac{1}{2} E (1 - \cos \omega t)$ (33)

e.m.f. between r' and $r'' = E \cos(\omega t - 45°)$ (34)

e.m.f. between r'' and $b = \frac{1}{2} E (1 - \sin \omega t)$ (35)

In the present case we need only consider the generator and motor actions which occur in the half armature during a quarter of a cycle, namely, from $\omega t = 0$ to $\omega t = 90°$. The integral of the generator actions in the three armature parts $a r'$, $r' r''$ and $r'' b$ during the specified quarter of a cycle divided by the duration of a quarter cycle, gives one-half of the inductively transformed power P.

Let A, B and C be the generator actions (motor actions when negative) in the armature parts $a r'$, $r' r''$ and $r'' b$ respectively at instant t. Then we have:

$$A = \tfrac{1}{2} E (1 - \cos \omega t) \, . \, i_a \tag{36}$$

$$B = \frac{E}{\sqrt{2}} . \cos (\omega t - 45°) \, . \, i_b \tag{37}$$

$$C = \tfrac{1}{2} E (1 - \sin \omega t) \, . \, i_c \tag{38}$$

From these equations we find

A is *positive* from $\omega t = 0$ to $\omega t = 90°$.

B is *negative* from $\omega t = 0$ to $\omega t = 90°$.

C is *positive* from $\omega t = 0$ to $\omega t = 90°$.

Therefore,

$$P = \frac{4}{\pi} \int_0^{90°} A \, . \, dx + \frac{4}{\pi} \int_0^{90°} C \, . \, dx \tag{39}$$

in which x is written for ωt.

Substituting the values of i_a and i_c from equations (32) in equations (36) and (38) and substituting the resulting values of A and C in equation (39) and integrating, we find

$$P = 0.1285 \, E I \tag{40}$$

That is, 12.9 per cent. of the energy which flows through a four-ring converter is inductively transformed by simultaneous and balanced generator and motor action, and 87.1 per cent. is conconductively transferred from the supply mains to the service mains.

7. Summary.

Energy Transformations in the Synchronous Converter.

Number of rings.	Per cent. of energy transformed by successive and unbalanced generator and motor action.	Per cent. of energy transformed by simultaneous and balanced generator and motor action.	Per cent. of energy conductively transferred.
2	31.83	9.517	58.65
3	0	23.58	76.42
4	0	12.85	87.15
Infinite	0	11.53	88.47

The calculation of these results demanded a great deal of painstaking computation; in fact, an amount which is very unusual in problems of this kind. These computations were done chiefly by Prof. Wm. Esty, to whom the author wishes to express his thanks.

8. Armature Reaction of the Many-ring Converter and its Effect in Distorting the Electromotive Force Curve of the Machine.

Consider the distribution of the magnetic field in the gap-space when the load on the converter is zero, and consider the distribution of field in the gap-space when the machine is delivering an amount of direct current I. Let f be the difference in value of these two fields at a point at angular distance β from the direct current brush a, Fig. 3. Let df be the variation of f in the element of angle $d\beta$. Let l be the magnetic length of the gap-space in centimeters, n the number of armature conductors per centimeter of armature circumference, and let i be the current in the armature conductors at the element $d\beta$. Then from the fundamental relation between magnetomotive force and current-turns, we have:

$$l \cdot df = \frac{4\pi}{10} \cdot ni \cdot d\beta$$

or

$$df = \frac{4\pi ni}{10l} \cdot d\beta \tag{41}$$

Substituting the value of i from equation (11) we have

$$df = \frac{2\pi nI}{10l} \cdot d\beta - \frac{8nI}{10l} \cdot \sin\beta \; d\beta \tag{42}$$

Integrating

$$f = \frac{2\pi nI\beta}{10l} + \frac{8nI\cos\beta}{10l} + C \tag{43}$$

In which C is a constant to be determined. By symmetry of winding and symmetry of distribution of current in two halves of armature, the value of f when $\beta = 0$ must be equal and opposite to the value of f, when $\beta = \pi$. Applying this condition to equation (43) we find,

$$C = -\frac{\pi^2 n I}{10 l} \tag{44}$$

which, substituted in equation (43) gives:

$$f = \frac{n I}{10 l}(2\pi\beta + 8\cos\beta - \pi^2) \tag{45}$$

This equation holds good on one side only of the armature. For expressing the values of f on the other side of the armature, the angle β must be measured from the brush b, Fig. 3.

If the electromotive force curve of the converter is determined by using an auxilliary concentrated winding of T turns of wire, then the amount by which the ordinate of the full load electromotive force curve exceeds the corresponding ordinate of the zero load electromotive force curve at the point β in volts is

$$e' = \frac{2 L T v n I}{l}(2\pi\beta + 8\cos\beta - \pi^2) \div 10^9 \tag{46}$$

in which L is the length of the armature in centimeters and v is the peripheral velocity of the armature in centimeters per second.

If it is desired to cut away a layer of thickness x from the pole face, so as to compensate for the armature reaction at full load, causing the machine to give the same electromotive force curve at full load as it previously did at zero load, this may be done and the thickness x is a function of β. In fact

$$x = \frac{f}{B} \cdot l$$

in which B is the field intensity in the gap-space at zero load. Therefore

$$x = \frac{n I}{10 B}(2\pi\beta + 8\cos\beta - \pi^2) \tag{47}$$

9. The Criterion of Reality of the Component Parts into which a Physical Aggregate is Resolved by Mathematical Analysis.

In the derivation of an algebraic expression for a determinate physical variable, two sets of conditions in general apply. 1. The condition or conditions which must be satisfied always and everywhere, that is throughout the interval of time and throughout the region of space over which the expression is to apply. These conditions are in most cases the requirements of the principle of the conservation of energy. 2*a*, The condition or conditions which must be satisfied at the boundary of the region and 2*b*, The condition or conditions which must be satisfied at the beginning of the time. Conditions 1 we will call *persistent* conditions. Conditions 2*a* may be *persistent*.

Consider as an example the problem of the vibration of an elastic string. The energy of the string is repeatedly transformed from kinetic to potential and back again, and the constancy of total energy is expressed by the well-known differential equation:

$$\frac{d^2y}{dt^2} = -v^2\frac{d^2y}{dx^2} \qquad (a)$$

which must be always and everywhere satisfied.

At the ends of the string we have the persistent conditions,

$$y = 0 \text{ when } \left\{\begin{array}{c} x = 0 \\ \text{or} \\ x = l \end{array}\right\} \qquad (b)$$

Any motion of the string is possible which satisfies these persistent conditions. Suppose that at the instant $t = 0$, the string is distorted into the shape represented by the equation,

$$y = f(x) \qquad (c)$$

The solution of the problem is

$$y = A\sin\frac{2\pi x}{l} + B\sin\frac{4\pi x}{l} + C\sin\frac{6\pi x}{l} + \ldots\ldots \qquad (d)$$

The various terms in this equation represent the component parts into which the actual motion of the string is resolved by the mathematical analysis of the problem. Each of these component parts satisfies all the persistent conditions of the problem and may therefore actually exist by itself, and there is no reason why we should not look upon each of these parts as real. *In general, the component parts into which a physical aggregate is resolved by*

mathematical analysis may be considered as real when each of these parts satisfies all of the persistent conditions of the problem and may exist alone.

Consider, as another example, the problem of the decay of current in an inductive circuit when the driving electromotive force is removed. Placing the rate of disappearance of electro-kinetic energy equal to the rate of generation of heat in the circuit, we have as a result the differential equation:

$$R\,i+L\frac{d\,i}{d\,t}=0 \qquad (e)$$

which equation must be always satisfied. Furthermore, at the beginning, the current has a certain prescribed value I. That is:

$$i=I \text{ when } t=0 \qquad (f)$$

The solution of this problem is

$$i=I\ (1-t+\frac{t^2}{1'2}-\frac{t^3}{1'2'3}+\frac{t^4}{1'2'3'4}-\ldots\ldots) \qquad (g)$$

in which R/L has been placed equal to unity for brevity. The various terms in equation (g) represent component parts of the current i, these parts do not satisfy the conditions of the problem; they cannot exist alone under the conditions of the problem, and therefore these parts cannot be looked upon as physically *real. In general, the component parts into which a physical aggregate is resolved by mathematical analysis cannot be considered as real when they do not separately satisfy the persistent conditions of the problem and when these parts cannot exist individually and separately under the conditions of the problem.*

Consider the case of the polyphase synchronous converter after it is in full operation. The persistent condition is equality of inflow and outflow of electrical energy and constancy of kinetic energy of armature. The problem of the determination of armature current under these conditions leads to expressions [see equations (11), (14), (21) and (32], which involve two terms. That is: the armature current is resolved into two parts and these parts correspond to inflowing alternating current and outflowing direct current respectively. This correspondence strongly suggests the physical reality of these two parts of the armature current; but as a matter of fact, neither part of the armature current satisfies the conditions of the problem, neither part can exist alone under the conditions of the problem, and therefore, these parts are mathematical fictions and not physical realities.

Discussion.

Dr. Sheldon:—I had the good fortune to see this paper before it was presented here, being chairman of the Committee on Papers, and therefore I have the advantage of the rest of the members present. I think that the great amount of work which has been put upon the paper ought to be recognized by the membership.

The conclusion which Prof. Franklin draws on the last page of this paper, is as follows:

"The armature current is resolved into two parts, and these parts correspond to inflowing alternating current and outflowing direct current respectively. This correspondence strongly suggests the physical reality of these two parts of the armature current; but as a matter of fact neither part of the armature current satisfies the conditions of the problem, neither part can exist alone under the conditions of the problem, and therefore, these parts are mathematical fictions and not physical realities."

This agrees perfectly with my understanding of the case, but I have not come to this conclusion by the application of his criterion. It seems to me that in any portion of a conductor that is supplied with e.m.f.'s of any sort there never can be but one current, and it is always in phase with itself. Now, I know that it is very convenient, when a wave is distorted because of hysteresis or anything else, to divide the current into two parts which are called wattless and watted, these components differing in phase by 90 degrees, but a physical conception of the flow of current in a circuit does not permit of such a division of the current. Consider an armature inductor of a converter. If any current at all flows in it, it must flow in either one direction or in the other. Now, if the current be flowing in the same direction as the e. m. f., which is being induced in that inductor, then that particular inductor is acting as a generator. If it be flowing in an opposite direction, then that particular inductor is operating as a motor. In the armature of any synchronous-converter motor and generator actions exist separately at different parts of the armature. They may be balanced, one being equal to the other but opposite in direction, but the motor activity is transmitted mechanically through the structure of the armature. In a three-phase converter it is present at all times, and the armature rotation is synchronous with the three-phase currents which produce it. Therefore, I cannot see how Professor Franklin's conclusion can be made to correspond with the statement on page 2, at the close of paragraph 1, which says:

"I give in a subsequent section of this paper a statement of the criterion which enables one to judge of the physical reality or unreality of the component parts into which a physical aggregate is resolved by mathematical analysis, and it suffices here to state that this criterion shows the physical unreality of synchronous motor activity and direct current generator activity

as component parts of the activity of the synchronous converter."

Professor Franklin has called attention to the fact that this subject is a difficult one to handle by this method. This is evident, and I think the subject can be treated in a much more satisfactory manner in the case of an actual converter, as well as of a theoretical converter, by making use of a series of current-time curves plotted one above the other, on abscissæ which represent times or angular positions of the armature core. Considering a bipolar machine, the shape of this current-time curve is to be derived by combining the direct current rectangular curve which changes its direction as the coil under consideration passes under a brush, with the alternating current curve. If the latter be assumed to be sinusoidal, as has been assumed in this paper, it will have a maximum value of twice the direct current output divided by n times the sine of π divided by n, where n represents the number of phases under consideration or the number of taps or slip-rings. These two curves are to be combined at a phase difference depending upon the angular position of the coil under consideration relative to the coil which is midway between two successive taps, and upon the power-factor. In an ideal converter at unity power-factor, the alternating current in all coils between two successive taps has a maximum value when the middle coil is under the center of a pole. This method may appear difficult, but for an actual converter it is not at all difficult. The drawing of the curves merely involves the use of a T-square and a templet which corresponds to the a. c. wave form. Draw one above the other, and on the same abscissæ, as many current-time curves as there are coils between two alternating current taps. Then, by placing the edge of a ruler vertically over any abscissa, the instantaneous values of the currents in that particular phase for any or all coils at that time can be read off, and for any other phase the currents at the same time can be taken from the same set of curves by displacement of the ruler by a proper number of degrees. I think that this method has some advantages over that of Professor Franklin. He has to assume that the e.m.f., which is induced in the inductors; that is, the distribution of flux, is cosinusoidal. In using the graphical method any distribution of flux may be considered, and it can be used for determining the power in any inductor in any position. Furthermore, the operation losses which are neglected in the analytical treatment can be considered. I have employed the graphic method just mentioned and have gone through the calculations for the three-phase converter, and I obtain practically the same results as Professor Franklin has found here; namely, that about 23 per cent of the energy is transferred by simultaneous and balanced generator and motor action. The coils which are acting as generators are, however, distinct from those which are acting as motors at the same instant of time.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 29, 1903.

COMMERCIAL ALTERNATOR DESIGN.

BY W. L. WATERS.

Deals with the chief elements entering into the design of alternators which affect the cost of the machine and gives a short account of the general tendencies in alternator design. Questions dealt with from the practical rather than from the theoretical standpoint.

The design of alternators has been treated times without number, but usually the commercial element in the design, *i.e.*, the relation of factory cost to selling price, has been left out. An engineer has been defined as a man who can do for one dollar what any fool can do for two, and this definition applies fairly well in connection with the design of machines. The man who can design the cheaper machine to satisfy a given specification is the better designer.

Speaking generally, there is no type of alternator that will compare with the internal revolving-field type with each pole carrying a separate field-coil of edge-on copper strap. The revolving-armature type is cheaper for high frequencies and low voltages. The inductor type is good for small 60-cycle high-speed machines, and the disc alternator without iron in the armature is an excellent machine for high frequencies. But these machines, though good enough in their own limited field, do not compare with the revolving-field type for general all-around work.

The revolving-field alternator took its present form about 1892 when Mr. C. E. L. Brown designed machines which were practically modern machines, while in 1893 Mr. S. Z. de Ferranti installed some 210 k.w. alternators at Portsmouth, England, which were of similar design to those of Brown[1]. Before this date

1. I understand from Mr. Brown that the firm of Brown, Boveri et Cie, deserve to some extent the credit for the design of the Portsmouth alternators, though Mr. Ferranti was the first to use edge-on copper strap for field magnets.

machines of this type were of a clumsy amateur design, and their performance was, generally speaking, very poor. And strangely enough, these two engineers after bringing out a first-class design, apparently abandoned further development, and their machines to-day are almost identical with their machines of ten years ago.

It has taken the different manufacturing concerns a long time to recognize the superiority of the Brown and Ferranti type for standard work, and it is practically only during the last three or four years that this type has been generally adopted. The result is that except for a few minor details, the construction of these machines has been improved very little since they were first introduced, while the excellence, from a commercial point of view, of the electrical design of Brown's early machines seems hardly recognized even yet by some engineers; and we have alternators on the market which are for a given performance decidedly more expensive than Brown's machines of ten years ago.

The armature frame in the Brown type of machine was simply a skeleton cast-iron frame for clamping the laminations together, and was full of large ventilating holes, while the ends of the armature coils stood out from the laminations quite free and exposed to the full windage of the magnet-wheel. The numerous holes gave excellent cooling effect, but they cut all the strength and stiffness out of the frame, and the armature had to be stiffened by a series of tie-rods or struts. This construction which saves material at the expense of labor, has become standard with German and Swiss firms, though on account of its unsightly appearance it has never found favor in this country. This type of alternator, shown in Fig. 1, has retained practically its original form up to the present and developments that have taken place have been mostly in the Ferranti type.

American and English engineers have followed the Ferranti type shown in Fig. 2, and made the armature frame stiff enough to stand without bracing. The trouble with this construction was originally the poor ventilation of the armature. Ventilating spaces were either not used or if they were, there was no proper circulation of air through them. The end connections on the armature winding or the ends of the coils, were packed tight together, or were closed in by cover-plates permitting no ventilation at all. Thus, the armature winding was usually the hottest part of the machine. So even allowing temperature rises of 45° C.,

the machines would not give anything like the rating they should, simply on account of the poor ventilation. And because, when American and English engineers took up the revolving-field type of alternator, the badly ventilated Ferranti type was adopted and the great importance of ventilation was not rec-

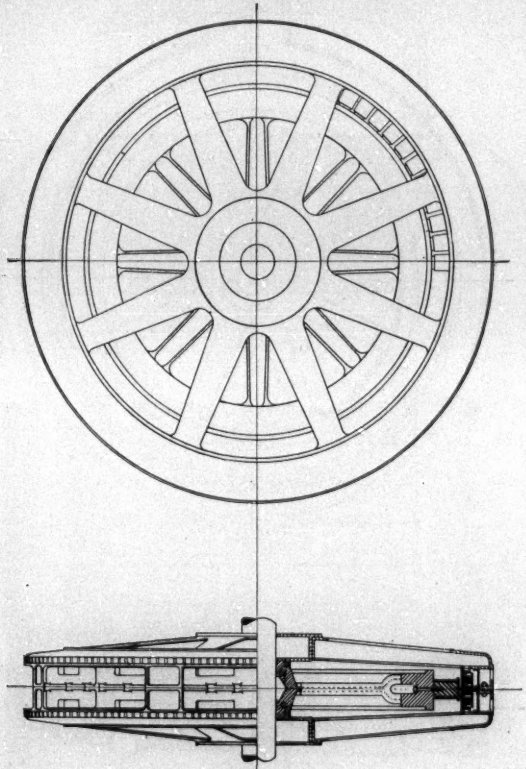

FIG. 1.

ognized, the development of alternator design in America and England has been comparatively slow.

The improvement in ventilation which has recently taken place in this type of alternator is really the greatest forward step that has been made and it has given the designer immense help in increasing the output of his machines.

Fig. 3 shows an old, badly-ventilated armature, while Figs. 4 and 8*a* show a more up-to-date well-ventilated machine. In Figs. 4 and 8*a* it will be seen that where the ends of the armature coils cross one another they are separated by an air-space and that the

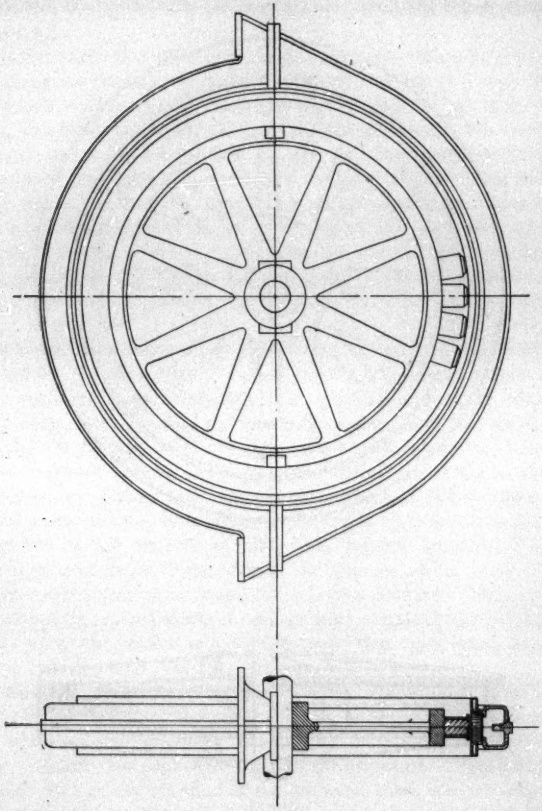

FIG. 2.

end covers are full of ventilating holes, so that there is a circulation of air all around the coils, and the armature winding instead of being the hottest part of the machine, becomes the coolest. The armature core is well provided with vent spaces both at the

center and at the ends, and the air passing through these vents is free to escape at the back of the core. This type of armature coil has the additional advantages that if lightning gets into the machine or a coil is burnt out, the damage is confined to one coil

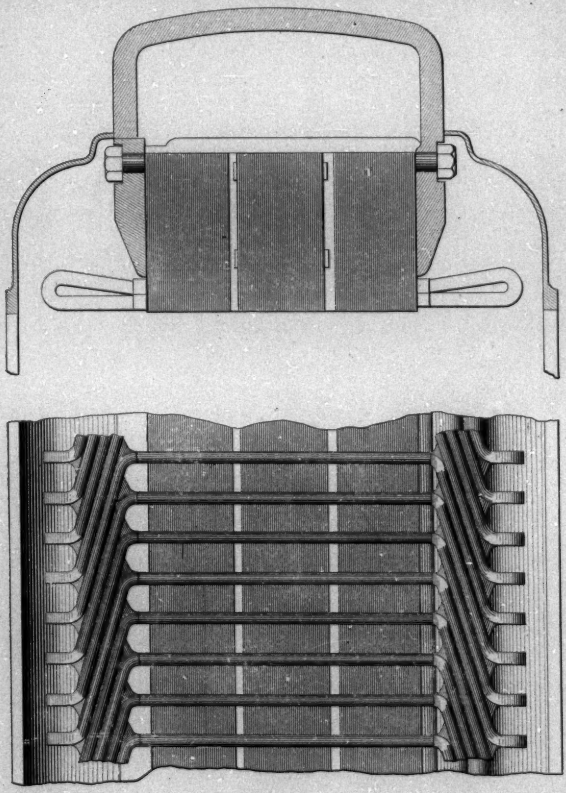

FIG. 3

and we do not have half a dozen burnt out as usually happens. Also, all the coils on the armature are alike and made on the same former.

The difference in the cooling effect between these different

types of machines may not look much on paper, but it means all the difference between a temperature rise of 45° and one of 25° on actual test. It means that we need only take into consideration efficiency and regulation in designing a machine, knowing well that if these are all right we can guarantee a temperature rise of 25°, even on low-speed machines.

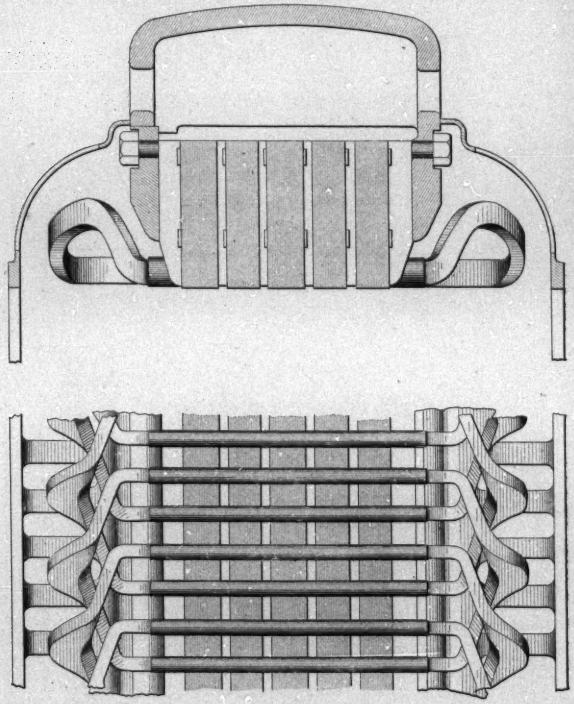

FIG. 4.

When designing any machine we have the choice of taking a large diameter and making the machine short, or of taking a small diameter and making the machine long. The difference in the cooling effect between these two is obvious from Figs. 5 and 6. In Fig. 5 the machine is small in diameter and long, the poles are

crowded together and the winding packed in. All the heat from the field-coils has to be got rid of from the small exposed surface at the ends of the coils. In Fig. 6 the machine is large in diameter and short, and practically the whole surface of the field-coil is available for cooling. In addition, the field coils being separated more from one another and the peripheral speed being higher, the cooling effect on the armature is much greater.

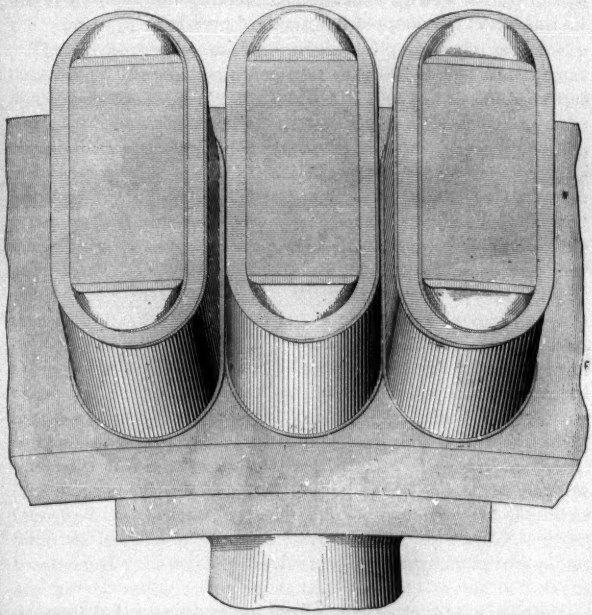

FIG. 5.

The machine in Fig. 6 being built on a large diameter will require heavier castings and present greater difficulties in handling, but the fact that the designer need not trouble about the temperature rise gives him so much more latitude, that he will easily offset this slight extra expense by a cheaper design generally and will in addition have a much cooler machine.

The difference in cooling between an alternator with armature and magnets as shown in Figs. 3 and 5 and one with armature

and magnets as shown in Figs. 4 and 6 is so perfectly plain, that it is quite surprising to find the poorly-ventilated type still on the market. The only inference to be drawn is that the firms building them have no tools capable of handling the larger diameter castings.

Coming to the electrical part of the design, the first thing to be decided is the specification to which the machine is to be built. The firm with which I am connected, having only recently taken up this work, has adopted for standard practice:

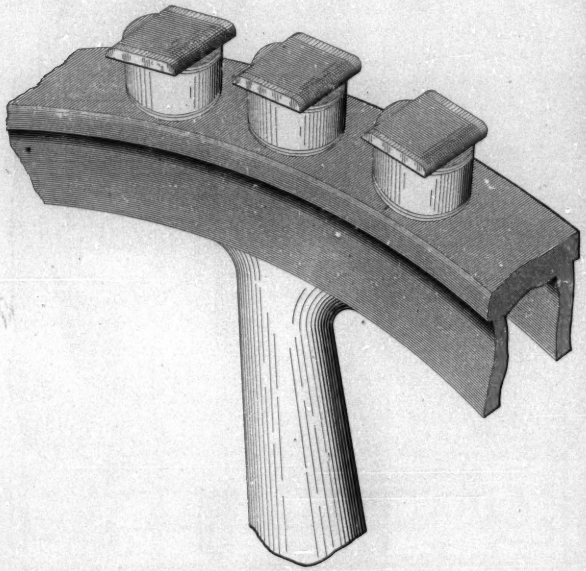

FIG. 6.

A temperature rise of 30° C. on a continuous full load run;

A temperature rise of 45° C. on 50 per cent. over-load for two hours;

A regulation of 5 to 7 per cent. according to the size of the machine;

And gives a guarantee that all machines will without damage give continuously 50 per cent. current over-load at $PF = 0$.

Given our specifications, we have next to decide what diameter we shall make the machine? What magnetic densities to take in the iron? What current density in the conductors? What percentage of the pole pitch shall the pole face be? What air gap? Of course, these questions can only be answered off-hand as the results of experience. But generally speaking we can, after a few trials, get down to the best design. We have only to consider the efficiency, the regulation and the cost, as with a good design the temperature need not be considered.

The efficiency of a machine within ordinary limits practically depends on the magnetic densities in the iron and the current densities in the copper. The higher the densities the cheaper and the less efficient the machine. The copper loss in the armature is usually between 1 and 2 per cent. Apart from the efficiency this is decided by the regulation, because when you are only allowing 5 to 7 per cent. drop on $P\,F = 1$, you cannot well have more than 2 per cent. of this as $C\,R$ drop. This means that in low-speed machines with a large number of poles, the current density in the armature is very low, while in high-speed machines with few poles the current density can be much higher. In practice it varies from 1200 to 3000 amperes per square inch. The iron densities do not vary much in standard machines, as the most economical densities are very fairly constant and independent of the speed, and any attempt to get higher efficiencies by decreased iron densities is likely to run up the cost very fast.

The best ratio of pole face to pole pitch is largely a matter of opinion. If it is large, say 70 per cent., then the e.m.f. coefficient (the Kapp coefficient) is reduced, and the total flux of the machine increased and hence the magnets made heavier. On the other hand we have more teeth to carry the flux so that for a given tooth-density the machine is shorter. But the armature core-plates are correspondingly deeper, so that the only saving is a slight decrease in the length of mean turn of the armature winding.

The larger the percentage of pole face to pole pitch the greater the magnetic leakage, and to a certain extent the less the synchronising power of the alternator. So that there is little to be gained by much variation of this ratio, and it seems advantageous to keep it low, say between 55 and 65 per cent.

The air gap is decided by the regulation of the machine. An immense amount has been written on various theoretical methods of calculating the regulation of alternators, but broadly speaking the regulation depends on the ratio of the ampere-turns on the armature to the ampere-turns for the air-gap.

In an alternator the armature conductors are cut by magnetic lines due to the armature current *i.e.*, the armature self-induction line, and by magnetic lines due to the magnet current. But the self-induction of the armature varies with the value of the current in the armature and magnets, and with the relative position of the armature and magnets. And the useful lines due to the magnets vary with the current in the armature and field on account of the permeability of the iron and the magnetic leakage. So it is obvious that the conditions to be taken into account are so complicated that it is quite impossible to treat them theoretically, without making so many assumptions that the results even when obtained cannot be directly applied. What a designer has to do, is to work through theoretically a few simple special cases himself and then the results will give him an idea on what lines to work, and by means of experimenting on a number of machines he gets an empirical method for calculating the regulation. Afterwards as he gets more and more experience with alternators, he introduces further refinements, and taking the regulation curves obtained by those empirical methods he corrects them a little by eye.

Speaking generally from a designers point of view, an alternator should be figured out for a certain regulation on a low power-factor, say $P F = 0$. For, if the machine is satisfactory, for low power factors it will be satisfactory, for $P F = 1$, while the converse is not true. Other things being equal, the larger the air-gap the better the regulation on the low power-factors. But the leakage-coefficient of the machine is an important factor, and this increases with the air-gap. The leakage-coefficient is, of course, taken into account in drawing the no-load saturation curve—but we have to remember that on full load of low power-factor the leakage-coefficient is much increased the—leakage is often doubled—on account of the extra ampere-turns required on the magnets to overcome the back ampere-turns on the armature. And if the leakage-coefficient is already high and if the density in the magnet iron is also high, we run a considerable risk of having the saturation curve bending over so fast that we cannot get our volts at all on loads of a low power-factor. It was just this trouble that made inductor machines fall out of use for low power-factor loads, as they are particularly sensitive to leakage and are always worked at high densities. Speaking generally, if the no-load leakage-coefficient of a machine is over 1.30, and if the density in the magnets is over 100,000 lines per

sq. in., the designer has to be very careful or he will get into trouble.

The regulation on noninductive loads is not affected by the length of the air-gap to the same extent as the regulation on low power-factors. So machines which are only intended for lighting or rotary converter work usually can be economically designed with a smaller air-gap, and hence smaller leakage, than machines for motor work.

In Europe practically every alternator sold has to run motors so that the regulation either for $P\,F = .8$ or for $P\,F = 0$, has to be guaranteed. In this country on account of the patent situation, induction motors are used only to a limited extent. As a result of this it has become standard practice to sell machines on a regulation guarantee for noninductive, rather than for inductive loads. This is very unsatisfactory. Almost every load that an alternator has to carry is to a certain extent inductive, *e.g.*, arc lamps, transformers on light loads, rectifiers, induction motors and synchronous motors unless the excitation is carefully adjusted. And as the regulation of an ordinary alternator on $P\,F = .95$ is about twice as bad as on $P\,F = 1$, it is obvious that a fairer guarantee would be to give regulation on inductive loads. Practically the only exception to this is the case of an alternator for use exclusively for running rotary converters. And even with a compound-wound rotary converter and an inductive line, the power-factor is usually low and the current lagging for low loads, and if the rotaries have to be started up from the a.c. side, a generator with poor regulation on low power-factors is very noticeable and may give trouble.

It is extremely difficult to measure the regulation for $P\,F = 1$ on any machine with good regulation, while on a large machine it is practically impossible. The result only comes in as the difference between two large quantities, and there are so many disturbing features that the result when obtained is not worth much. On the other hand, it is quite easy to measure the regulation on a very low power-factor by taking a second machine and running it as a synchronous motor, the first one running as a generator. And then varying the excitation of the motor and generator till we get full-load current flowing at full-load voltage; the power-factor in the test will be very low and can with sufficient accuracy to be taken as being zero.

Alternators can be designed so as to satisfy a pretty good regulation specification for noninductive loads and yet be almost

worthless for carrying loads of low power-factor. And as such machines can be made cheaper than if they had to give a reasonable regulation on inductive loads, there is a temptation for manufacturers to take advantage of the fact that the regulation is only guaranteed on $P F = 1$, and to put in one of these cheaper machines. And it is probably this fact that is responsible for the number of alternators having poor regulation on low power-factors, that have been installed in this country. It would certainly an be advantage from the customer's point of view and probably in the end from the manufacturer's point of view also, if the regulation were guaranteed for a load of low power-factor. This would make it necessary from the commercial point of view to alter somewhat the lines on which modern alternators are designed, but the cost of the machines would not necessarily be much increased. A modern alternator gives, say, 7 per cent. regulation on $P F = 1$, and 22 per cent. on $P F = .8$. When running with a normal power factor of about .85, and a regulation of about 17 per cent., it does not do the station engineer much good to know that if he had a noninductive load he would have good regulation. Such a machine could be re-designed on somewhat different lines, so as to have 6 per cent. regulation on $P F = 1$, and 12 per cent. on $P F = .8$, and about $\frac{3}{4}$ per cent. lower efficiency without increasing the cost more than 10 per cent. Such a machine would be much more satisfactory for general work and could probably be sold for considerably more than the machine designed only for work on noninductive loads.

Other things being equal, the regulation of an alternator is better the more saturated the magnet circuit; this applies to low power-factor loads as well as to high. This can be considered simply as an experimental fact, or the explanation can be accepted that the voltage drop in an alternator is partly due to the reaction of the armature ampere-turns, and that the effect of a definite percentage change in the ampere-turns is less when the magnets are saturated than when they are not.

Obviously the part of the magnetic circuit to saturate is the magnet core, as the less its cross-section the less its perimeter and the less the weight of the magnet copper. In the type of magnet, shown in Fig. 7 it is impossible to saturate the pole core, and the large amount of iron and copper necessary always makes this design needlessly extravagant. It, however, possesses the advantage that the voltage can be raised 25 or 30 per cent., if

desired, to compensate for an extraordinary line drop. Usually, however, it is sufficient if an alternator is capable of having its voltage raised 15 per cent. when carrying full load.

When designing an alternator for a given output we can take either a strong armature and a weak field, or a weak armature and a strong field. And generally speaking, the stronger the armature we work with the cheaper the machine but the worse the regulation. So to design cheap machines with good regulation, we have to take advantage of everything that will better our regulation, *i.e.*, we must work with a long air-gap and we must saturate our poles. But a long air-gap means large leakage, and as I pointed out before a machine with large leakage and saturated poles is the most difficult machine of all to design. And to make a uniform success of these machines, the designer must have had considerable experience with the type of machine in question, and must be a very careful worker. In fact, when I first started designing alternators I was told to put plenty of iron and plenty of copper into the magnets and then I would be safe. I followed this advice and was always safe with my machines. I think for a beginner the advice is very good and that he could not do better than to start in with a conservative and simple design like that shown in Fig. 7. But for a designer who has had considerable experience, it is worth while to attempt cutting things fine, because there is quite 20 per cent.in the cost to be saved by doing so.

We are working with a large air-gap and yet wish to keep down the leakage. There are several things which will help us in this, but making the pole pitch large and decreasing the length of the magnet pole are the most important.

Making the pole pitch large means making the machine larger in diameter, and shorter. Beyond certain limits this increases the cost of the machine, and it is a question to be decided by the designer as to when the advantages obtained from the larger pole pitch are offset by the increased diameter and weight of the castings.

Decreasing the length of the magnet pole core decreases the leakage. Decreasing this length means decreasing the radiating surface, increasing the depth of the magnet winding and hence increasing the length of mean turn of the magnet coil a little at the same time, and slightly decreasing the ampere-turns for the magnetic circuit. If we use large pole pitches, giving plenty of space between the poles and short armatures and high peripheral speeds, we can easily take care of the increased temperature due

to decreased radiating surface. So that the limiting factor in decreasing the length of the pole core becomes the increase weight of copper due to the increased length of the mean turn of the magnet winding, caused by the extra depth of the winding. With good design we can usually cut down the length of pole core to about 1 inch for every 1500 ampere turns required on full load. So that our leakage-coefficient will generally not exceed 1.25, which is not excessive.

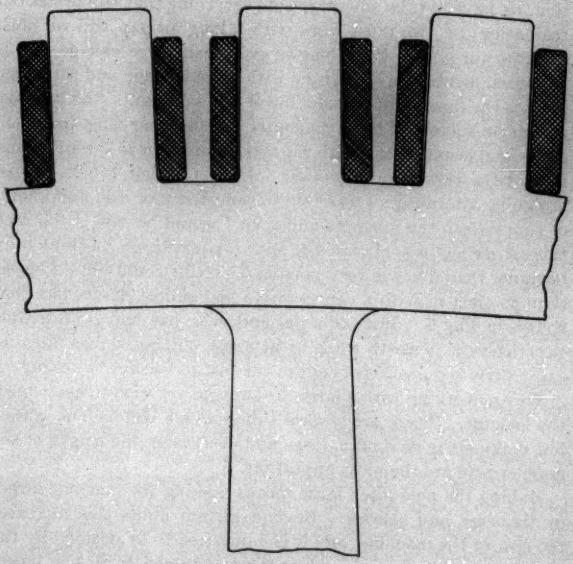

FIG. 7.

To show the effect of these various points on the design of a machine let us take a definite example.

Output 750 kw. 60 cycles, 100 r.p.m., 72 pole, 2200 volt. Specification to be:

Efficiency at full load 95 %
Regulation 7% for $P F = 1$
" 16% for $P F = .8$
" 25% $P F = 0$

Temperature rise on full load $PF = 1$, Armature 30°C., Magnets, 20° C. (To take care of the increased excitation on loads of low power factor.)

A is a machine which has a pole pitch and diameter large enough to use round poles, and has saturated pole cores. It has a strong armature and strong magnets.

B has a smaller pole pitch, and is a longer machine and has unsaturated fields. It has a fairly weak armature and field, and the magnet winding is crowded.

	A.	B.	C.
Internal diameter of armature	207″	161″	207″
Length of armature core	6½″	13½″	6½″
Pole pitch	9″	7″	9″
Air gap	5/16″	¼″	5/16″
Peripheral speed	5400	4200	5400 r.p.m.
Slots per pole	6	6	6
Turns per coil	5	3	4
Magnet core section	round	rectangular	round
Induction in magnet core	110000	95000	110000
Regulation $PF = 1$	7%	6.8%	5.6%
$PF = .8$	15.5%	16%	10%
$PF = 0$	24%	25%	16%
Losses magnet C^2R	12500	8500	17000 watts
Armature C^2R	10700	7250	12000 "
Iron loss	15200	24000	19300 "
Efficiency	95.1%	95.0%	94.0%
Temperature rise of armature	22°C	30°C	26°C
" magnets	15°C	16°C	26°C
Weight magnet copper	1800	3800	2300 lbs.
" " poles	1420	4500	1780 "
" " wheel	14000	15000	16000 "
" armature copper	1425	1200	810 "
" " laminations	5500	7500	6600 "
" " frame	22000	18000	22000 "
Cost of above material	$1,645	$2,150	$1,710

So on the principal items that enters into the cost of material, the saving is about 25 per cent. Probably the saving of the cost of the complete machine would be about 20 or 25 per cent. The designs of these two machines are a little exaggerated but they show very well the saving in cost that can be made.

C is the same machine as A but designed with a weaker arma-

ture, so as to have better regulation especially on low power-factors, at the expense of a lower efficiency. The cost is about the same.

The chief points for a cheap design are strong, saturated magnets, a reasonably large pole pitch, and as large an air-gap as can be run without excessive leakage. In machines of small output with a large number of poles, it is impossible to get a really cheap design. The diameter is decided by the number of poles and it is no use making the machine less than 5 or 6 inches long, so the cost does not come down very much with the output. Generally speaking, if the ouptut of the machine is less than 10 kw. per pole, the design is unnecessarily expensive, while machines in which the length of the armature is about equal to the pole pitch usually come out the best. It is for this reason that 60 cycle alternators for small outputs and 120 or 133 cycle alternators of all outputs are usually made belt-driven. The saving in cost by this means is often 50 per cent. In continental Europe where 50 cycles is the usual practice, belt-driven alternators have never met with much favor. The universal custom is to direct-connect the alternator to a low-speed engine. The result of this has been that the fly-wheel type of alternator has practically become standard; the poles of the alternator are simply bolted to the rim of the fly wheel. This type allows considerable saving in cost in small 50 or 60 cycle machines and possesses so many other advantages that it is being gradually introduced into this country.

Alternators for direct connection to steam turbines have lately come into prominence. The chief consideration in these machines is, of course, the high speed at which they run.

In order to keep down the length of the machines, they have to be made with the diameter as large as possible, so that the peripheral speeds run from 12000 to 15000 feet per minute. The tensile stress in the steel is not so bad, the chief difficulties lie in getting the mechanical strains on the insulation of the rotor to be taken in such a way that the insulation is not damaged, and in getting the rotor properly balanced and to run without making excessive noise.

The electrical design is much the same as that of belt-driven machines, except that the speed being so high the efficiency is very good, so that the densities in the armature can be considerably higher. The pole pitch and the ampere-turns on the armature being large the magnets are of necessity very strong and the

air-gap large, and it is as much the magnetic leakage as the difficulty of getting sufficient cross-section in the magnet iron to carry the flux that decides the output of the machine. In these machines just as well as in low-speed machines, strong magnets and high density in the magnets give cheap machines. But good mechanical design will have far more effect on the cost than would be the case in a low-speed machine.

When starting to work out a machine an experienced designer can guess pretty exactly the best diameter on which to build it. And he knows from experience approximately the number of

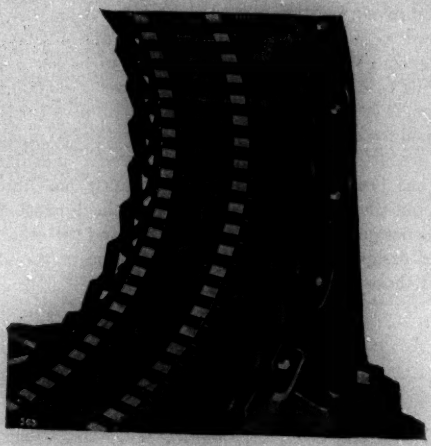

FIG. 8.

ampere-turns he can take per inch periphery on the armature for a machine of a given pole pitch and type. This gives him at once the number of turns on his armature and the ampere-turns on the magnets. He then completes this first rough design, and working out its performance curves he can usually see very quickly in what way to improve it so as to obtain the best design possible under the circumstances.

The speed and frequency are the chief factors in deciding the design of a machine, but the voltage, the condition of operation, the equipment of the factory in which it is to be built, the facilities for obtaining castings and for shipping the completed machine, all are points which affect the design and have to be

considered by the practical designer, since the prime object in a commercial design is rather to make profits for the manufacturing company than to produce the most perfect machine. The points that have to be taken into consideration are so numerous and varied that it is impossible to give general rules for practical design. All that can be done is to give general directions and after that it is a question of ability and experience till the engineer can produce the best results.

Neglecting for a moment the designs of Mr. C. E. L. Brown, the greatest change in the design of alternators in the last ten years is the improved ventilation and the increased magnet strength. In 1893 we were working with air-gap densities of 25000 to 30000 and magnets giving 3500 to 4000 ampere-turns per pole on full load, while to-day we have air gap densities of 60,000 to 70,000 and magnets giving anything up to 20,000 ampere-turns per pole on full load for ordinary belt-driven or engine-type machines and up to double this on steam-turbine-driven machines. The change has been made so gradually that it has hardly been noticed, but the effect can be seen if I give the dimensions on two machines designed and tested, one in 1894 and the other in 1903. Both the designs are typical of the condition of the alternator design at those dates.

	1894 Machine.	1903 Machine.
Output	50 kw. Single-Ph.	275 kw. 3-Phase.
Speed	600 R.P.M.	600 R.P.M.
Cycles	60	60
Type of magnets	Lauffen Type.	Standard Rev. Field Type.
Internal diameter armature	37″	38″
Length of armature laminations	10½″	10″
Armature ampere-turns	1380	1050
Ampere-turns on magnets	4700	7500
Efficiency	90%	94%
Regulation $PF = 1$	11%	5.5%
" $PF = .8$	Would not give volts	14%
Temperature rise of armature	31°C	23°C
Total weight of copper	730 lbs.	680 lbs.
Total weight of machine	7400 lbs.	11000 lbs.
Total cost of material (2 bearing machine)	$455	$490

The output has come up about four times and we have a much better machine as regards performance, and the cost is about the same. The older machine having such a low output needs a lot of unnecessary material, simply to reduce the losses and to give a reasonable efficiency. While in the large machine we can afford a far higher loss without spoiling our efficiency, so that the weight of material is really not so much more and the better mechanical design has made the cost of material in the two machines about the same. Speaking generally, the whole result has been accomplished by using stronger magnets and higher densities throughout.

Alternating current design has rather stagnated of late on account of the limited competition, and most of the recent developments have come from the other side of the water. But I think there is enough in this paper to show that from the point of view of dollars and cents, it certainly pays to spend time and ability pretty lavishly in designing alternators.

Discussion.

Mr. Waters:—I think this is a suitable opportunity to emphasize the advisability, from a commercial point of view, of guaranteeing alternator regulation for power factor = 0 rather than for power factor = 1. It is true that the Institute Committee on Standardization has formulated a rule for calculating the regulation on non-inductive loads from a short-circuit test, but I think there is a general concensus of opinion among alternating current designers that the rule is very unsatisfactory, and that for certain classes of alternators it gives results which are absurd. And I suggest that it would be a good deal more to the point if the Committee would recommend that the regulation be guaranteed for power factor = 0, as this gives the behavior of the alternator under the worst possible condition, and in addition a direct test can be made to determine whether or not the alternator fills its guarantee, instead of relying on a calculation based on arbitrary assumption, the accuracy of which there is nobody to vouch for in cases of dispute.

Mr. David B. Bushmore:—The generator is one of the important elements of a transmission system. The regulation of the system is largely dependent on that of the generator.

There are certain peculiarities of high voltage power transmission which differentiate, to some extent, the requirements which a generator must fulfil from those in other kinds of work. The voltage of the line, and sometimes of the generator, is high. The long lines offer a great many opportunities for trouble, so that grounds and short circuits are of frequent occurrence, and the number of severe strains on the apparatus is large. Some systems have a considerable proportion of the output utilized by induction and synchronous motors in large units, which, when used for mine hoists, or in case the latter are started by being thrown on the line, make the problem of satisfactory lighting one requiring care. Lightning troubles are more frequent as the length of line is increased and storms are of greater violence in mountainous countries.

Δ or Y Connections.

The question as to which type of connection is better is important. The reasons which apply for and against each type of connection for transformers apply with equal force to the generator. One point of especial interest is the effect of a Δ connection in a system having a pronounced third or ninth harmonic. Capacity in the system tends to amplify, in the current curve, any harmonics which may exist in the original e.m.f. wave. Now in a generator armature, or transformers having a Δ connection, the third harmonic instead of having a phase difference of 120° in the different legs is directly in phase as shown in Fig. 1, and tends to send a circulating current around the delta. In one experimental alternator the current in the delta was full load value. As this current is limited by the resistance and inductance of the generator and not by the "synchronous impedance"

it is less in machines of high inductance. Modern generators are built with wave forms which follow so closely the sine law that this fact is of perhaps more theoretical than practical interest and yet should be borne in mind as a possible explanation of phenomena occasionally found in practice. A small amount of static capacity is desirable in a generator and it should be less with a Y than with a Δ armature connection owing to the fewer turns on the armature. A bad short circuit may burn out two-thirds of a Y connected armature and but one-third of a Δ.

It is especially with regard to regulation that generators should be suited to the line and conditions of service.

Good regulation is desirable for the following reasons:

The voltage will not rise to so great a value on sudden opening of receiver circuit;

Less careful attendance is necessary as the change in

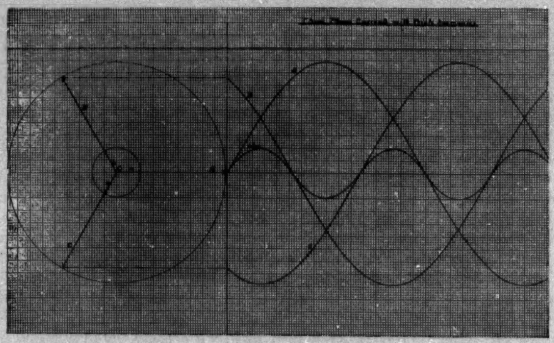

Fig. 1.

exciting power for variation in load and power factor is less;

Induction and synchronous motors may be thrown on line with less disturbance.

Fair regulation gives the following characteristics:

Disastrous results from short circuits are prevented;

Generators have stronger synchronizing power and make better synchronous motors;

The charging current raises the voltage at the generator terminals.

The short circuit current is less and the operation of automatic devices for opening the circuit may be easier;

Better efficiency and a less expensive machine may be had than when the regulation is better;

More even division of load with less cross-current and better parallel operation;

The operation of lightning arresters will be more satisfactory.

Bad regulation produces:

Abnormal variation in excitation and bad regulation of system.

Excessive rise of voltage due to charging current:

Ability to run machine on short circuit momentarily without injury;

Disastrous effects from sudden inductive loads.

Occasion is here taken to call attention to a point in theory in which an error may have been made by some writers. It has been considered by many that when the iron is saturated, in either the armature teeth or the pole corners, that the cross or distorting ampere turns weaken the field by being unable to increase the flux as much in the strengthened pole corner as it is decreased in the weakened pole corner. So far as is known to the author, every writer, with the exception of Mr. C. C. Hawkins, has adopted this view, and a number of theories and diagrams for predetermining alternator regulation have been based upon it.

No experimental proof has been shown to uphold it, but, on the contrary, much that exists points the other way. Brush lead in a continuous current dynamo and power factor in an alternator, are in very close correspondence. In tests which have been made on field exploration of continuous current generators and speed tests on separately excited motors, both with local saturation and the brushes at the neutral, the evidence, while not conclusive, points to the fact that the field is not weakened by armature reaction under that condition. In an alternator, with current in phase with the no load e.m.f., which could be obtained with a leading terminal current, the drop in the armature should be due only to true armature self induction and resistance, except for minor causes, as variation in power factor of field. That is with non-inductive load, in armature of an alternator and with brushes at neutral in continuous current generator, the cross field formed bv the distorting ampere turns of the armature represents pure armature self induction and is not interlinked with the exciting turns. The number of magnetic lines added on one side of the pole must exactly equal those subtracted on the other, owing to the different densities, in both air and iron, the magneto motive forces, and not the fluxes, are unequal on the two sides.

The wave form of the generator should be a sine wave and the amplitude of any harmonic should not exceed from 3 to 5 per cent of the fundamental. The various pieces of apparatus through which the energy passes and the capacity of the line, transformers and armature, will all tend to cause distortion.

RALPH D. MERSHON:—I have not seen this paper before, but there are few things mentioned in it which have struck me and with which I cannot quite agree. One is the temperature rise on full load. I do not see any use in a temperature rise as low as

30°C. I do not think any of us will get anything from the electric companies that we do not pay for, and I think we will pay for a 30° rise all right. If not when the company first starts in business, we will later. A rise of 40° or 45° is certainly safe with modern insulation. I think the practice of the European engineers has a good deal to commend it. They ask for a machine that will rise 40° under full load, and that is what they mean. They pay for a machine that rises 40°, and do not pay for anything more.

There is a statement made here in regard to the regulation. The author says, "In Europe practically every alternator sold has to run motors so that the regulation either for power factor .8 or for power factor 0 has to be guaranteed." Judging from some generators I have seen lately it must in some cases be guaranteed pretty high. I saw not long ago some European alternators of from 1200 to 2000 h.p. capacity. They were some of the most beautiful machines mechanically I have ever seen, but electrically I thought them bad. When I say "bad," I mean from the standpoint of our ideas as regards regulation. Those machines must have had a very poor regulation on any power factor less than unity, and I do not believe we could have gotten any satisfaction from them in our plants with a power factor of .8; certainly not with the attention that is ordinarily given here to the operation of machines. There was another evidence, in most of the European plants I saw, that the regulation could not have been very good. It was the switching arrangements. In many cases there were no switches intended to break the load in case anything happened and in no case did I see a switch which could have handled a short circuit if the generator had had stiff regulation. In most cases on asking what was done when a short circuit occurred, I was told that they shut down either all of the plant or that portion of it which happened to be feeding the line on which the short circuit occurred.

HARRIS J. RYAN:—I want to say just a word in behalf of the Committee on Standardization. At the outstart of the present year the Committee appointed one of its members, a well-known consulting engineer, to take up with the electrical engineering profession in this country the regulation of alternators, with a view to making a new formulation of the wording and specification of procedure in Section 71, I think it is, of the Standardization Code, or report, as it is variously called; and that member of the Committee in taking up this work—and he did a great deal of work in this respect—found that as yet, at least at this immediate time, the concensus of opinion of the profession was such as not to be prepared to accept any one wording that could be formulated to suggest to the INSTITUTE to be substituted for the present wording. The matter is well in hand and at a comparatively early date we hope to be able to report a suggestion for a satisfactory wording of that section.

MR. WATERS:—There are one or two points in Mr. Rushmore's remarks which I do not quite agree with. Mr. Rushmore calls attention to the fact that in designing alternators for running on long transmission lines, we have to allow for the numerous short circuits which take place, thereby, I suppose, intimating that an alternator with good regulation was hardly satisfactory for this work. I think that this is altogether wrong. When you have a short circuit on the system, the general practice is either to burn it out or else have the circuit breakers cut it out. If you have an alternator with bad regulation and leave it on the line, it merely means that the pressure decreases, so that the motors fall out of step and the plant shuts itself down, the voltage not being sufficient to burn out the short circuit.

In connection with inductor alternators, I did not mean to suggest that an inductor alternator cannot be made with good regulation. They certainly can. If you take a 200 k.w. alternator and rate it down to 100 k.w., you will probably get a machine with very good regulation, but it will not be a commercial machine. My paper was dealing with the question of dollars and cents in connection with alternator design, and I say that a revolving field alternator designed as I have suggested is simply above comparison with an inductor alternator on a question of cost, the difference being a matter of perhaps thirty per cent.

[COMMUNICATED AFTER ADJOURNMENT BY MR. W. L. WATERS.]

Referring to Mr. Mershon's remark that he did not know that the temperature rise of a machine was determined by the mechanical design. I would point out that the temperature rise depends on two things: The watts to be dissipated in the machine and the rate at which they are radiated. The watts to be dissipated depend on the output of the machine and on the efficiency; and the efficiency is decided by the market standard, being a commercial rather than an engineering question. So we can say that the watts lost in a machine are independent of the design, and hence that the temperature rise depends only on the facilities for radiating a given number of watts, that is on the ventilation or mechanical design.

[COMMUNICATED AFTER ADJOURNMENT BY DR. SHELDON.]

From calculations, which have been carefully gone over since the presentation of Dr. Franklin's paper, and which I am firmly convinced are correct, the value of the amount of energy transformed by simultaneous and balanced generator and motor action, in the case of a 4-ring converter, is about 18 per cent. and not 12.85 per cent., as given in the paper. Further calculations confirm the values given in the paper for the single-phase and the three-phase converter.

It seems to me unfortunate that the autotransformer should have been chosen and used as analagous in operation to the converter, especially in the effort to draw any conclusions as to

the physical reality or unreality of motor and generator actions. The rotating part of the synchronous converter, through its kinetic energy, acts as a medium of conversion between the electrical energies of input and output. The core of the autotransformer, through the potential energy of its magnetic flux, performs a similar service. Therefore the presence of motor activity is to be looked for and expected in the converter and its absence can be postulated in the case of the autotransformer. This follows also from a consideration of the field magnets, which are present in the case of the converter but are wanting in the autotransformer. Furthermore, the inductive relations between the different coils on the core of the autotransformer are at the basis of its operation and therefore the self and mutual inductances are made comparatively large, while the inductive relations between the coils on the core of the converter armature are insignificant factors in its operation and, therefore, the self and mutual inductances are intentionally made small. In fact, the differences between the constructions and the methods of operation of the two machines are many and fundamental.

Dr. Franklin, in applying his criterion of reality to the polyphase synchronous converter, states as the "persistent condition" the "equality of inflow and outflow of electrical energy and constancy of kinetic energy of armature." He erroneously includes, in his treatment equation (14), which represents, by the two terms of its second member, the two components of the armature current in a 2-ring converter. In this machine there is an inequality between inflowing and outflowing electrical energy and there is not a constancy of kinetic energy of armature. The "persistent condition" may be better stated, in that both single and polyphase converters are included, as follows: *A constant difference between the inflow of electrical energy and the kinetic energy of the synchronous converter armature which is equal to the constant outflow of energy.*

Dr. Franklin states in substance that the component parts of an equation do not stand for physical realities unless they separately hold for all the "persistent conditions" of the problem, and may exist alone all the time under said conditions. He concludes that the component parts of the equations representing motor and generator actions in a converter cannot exist separately all the time and that there are, therefore, no physically real motor and generator actions. By the same token his "Criterion" cannot be valid unless good for every instant of the persistent conditions present in a converter. Now, in a 2-ring converter when the a.c. taps are under the d.c. brushes the exact conditions are present within the machine that are found in an ordinary continuous current motor, and no others. From this it is evident that physically real motor action must be the action that is going on at that time. After a revolution of the armature through 90° the exact conditions of an ordinary continuous current generator are present, and no others. At that time there must be physically

real generator action going on. All of this is contrary to the conclusions derived by Dr. Franklin from the use of his "Criterion," and they suggest that its use fails to give a convincing consciousness of the physical reality or unreality of the actions which can be represented by the component parts of an equation for a physical aggregate.

PRESIDENT SCOTT:—The paper on Institute Branch Meetings, prepared by Mr. Calvin W. Rice, the chairman of the Committee on Local Organizations, will be read by Professor W. E. Goldsborough, who is also a member of that committee.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, June 29, 1903.

INSTITUTE BRANCH MEETINGS, THEIR ORGANIZATION, DEVELOPMENT AND INFLUENCE.

BY CALVIN W. RICE.

To any one looking over the work of the INSTITUTE of this year and comparing it with that of previous years, there will immediately appear an increased scope of usefulness of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. The situation is seen at a glance by looking at the last pages of your program for this meeting, showing the magnificent array of local branches installed and regularly conducting meetings. The credit for the activity is very much due to your President, Mr. Scott. It has been one of the features of his year's work, the broadening of the influence of the INSTITUTE, and on a very high plane.

The idea of branch organizations was given a number of years ago, and the Secretary, Mr. Pope, made a report on it. However, the President at that time did not favor the movement as he was fearful that it would weaken rather than strengthen the INSTITUTE. Some thought has been given to this contingency, yet at no time has the Committee considered it serious. We have gone ahead on the principle that the work is right, that it is for the benefit of the INSTITUTE and of Engineering and that if we properly conduct our meetings, there will be strength in them; and one need not fear that the movement will promote separate engineering societies in the different cities which will divorce themselves from the central organization.

The oldest local branch is the one in Chicago. This was established in 1893, and has been regularly maintained. An average of 7 meetings has been held each year with an average attendance this last year of 70. The next one to be established was at Minneapolis, April, 1902. The larger number, however,

were established in the fall of last year and the spring of this year. The largest number of meetings held was at the University of Wisconsin where during the last year 30 meetings have been held.

It was thought at the beginning of the year that the organization of local branches should be in accord with a definite prearranged plan and it was proposed to map out a specific plan to be adopted by each branch. On account of pressure of business, the Committee on Local Organization was unable to go into all the details of organization, and it has since proved that perhaps this was an advantage, rather than a detriment. Greater spontaneity has thereby been secured and a variety of successful methods have been developed adapted to various conditions.

I wish that time permitted the reading of all of the reports which have been received from the several branches. These have been prepared with care; sometimes the entire Executive Committee met together to formulate the report and recommendations, and the INSTITUTE owes its thanks to them for all the work they have done.

Some of the principal features that one notes in reading the reports and in our general observation of the progress of the year, is that, whereas meetings in New York may be technical or special, meetings in Local Branches must be general. In all the reports, one finds that to maintain interest, there must be more than one set of people on whom we may draw for our audience. Quite a number advocate very properly, joint meetings with other engineers. Some others are positive that in their locality our meetings should be conducted independently of other societies, but this opinion is in the minority.

A very interesting feature of the work has been the large attendance of non-members of the INSTITUTE at the meetings. Outsiders are attracted to the meetings. Ten or a dozen members may manage a meeting of a hundred. This illustrates the power we have within us if actuated by the right principles and on the right plane.

It is generally suggested, as mentioned above, that all engineers, regardless of their affiliations, should be invited to our meetings. It may be that we do not care to join in their meetings, but we should invariably invite all engineers to and make them welcome in our meetings.

It has been almost universally reported that the papers of the last year have been so diversified and of such an interesting char-

acter that in but one or two cases has there been any necessity for papers to be prepared on local subjects in order to maintain interest. I think this is speaking a great deal for the variety of subjects and general usefulness of the papers presented during the last year. Special thanks also are here given, and we trust the word will be passed along to the speakers themselves, to those authors who have not only inconvenienced themselves to write papers, but to come to New York to read them, and have again read them at some of our branches, all of which has tended to promote the very best interest in the INSTITUTE work.

A very good suggestion is that in the branch meetings the New York papers be read by abstract only, and that well-informed men be called upon to give the abstract of the paper and of the original discussion. It is quite uniformly agreed that the discussion, when the same as that in New York, need not be printed, but it is recommended that the Editing Committee give credit to each speaker who gave opinions along the same lines. One good suggestion is that the editing of each Local Branch be done the next day after the meeting by the Committee in charge of that Branch. Another suggestion is that all papers should be sent to the Local Branches with the abstract prepared. These abstracts and the papers themselves to be sent out earlier, and still greater efforts should be made on the part of the Committee on Papers the coming year to try to get the papers sent well in advance of the meeting.

One of the evidences of the substantial work done is the request even now for next year's program and also in the suggestion that in Universities the members of the junior class be put on the committee to take part, so that next year a working committee will already have had some experience.

One special point made in the suggestions received is that definite responsibility for the success of the meetings should be placed upon some one individual. He may have a Committee to assist, but some one person should feel that the success of the meeting is dependent on him.

An indication of the work of the year has been the increase in membership, the work of these branches being carried on hand in hand with the Membership Committee and the other influences of the INSTITUTE. In the May announcement, you will find the increase in membership in half a dozen cities alone, where we have local branches, has been about 350. The total increase for the year up to May 1st has been stated in the April

announcement in the neighborhood of 850. Whereas it would not be fair to assume that the whole credit should be given to any one feature of the INSTITUTE, still, it is hoped that the INSTITUTE will give due credit to the hard work of the various local Executive Committees and secretaries who have kept up the interest throughout the year in the meetings at various branch centers and thus made the INSTITUTE felt as it never before has been.

At the beginning of the year an appropriation of $1,000 was asked to carry on the work of the season. The expenses of the year, as reported in the Secretary's statement of June 19th, have been $849.64. It has been the uniform practice to offer to meet the reasonable and necessary expenses of Local Branches, it being considered that we should do this, for the reason that the members that have subscribed their yearly dues should not be further called upon to contribute. At one point, the Local Membership have been assessed one dollar by their own Committee; such contributions should be voluntary rather than obligatory.

From a financial point of view, therefore, upwards of 300 members have been either influenced or encouraged to join the INSTITUTE, due to the activity of the Local Organizations, bringing into the INSTITUTE immediately $1,500 and a probable permanent annual income of $3,000, and at an outlay of less than $1.000; this without reference to the Student enrolment. This statement is simply to show that the movement has been self-supporting, to say nothing of the remarkable increase of influence and power of the INSTITUTE.

I cannot do better in closing this report than to quote the remarks of the secretary, Mr. Philander Betts, of the Washington Branch: " We are unanimous in our desire to have our meetings so conducted that they will become a common meeting ground for all engineers."

Discussion.

President Scott:—At the beginning of the year when it occurred to me that the Institute might work in a field in which it could come in contact with the college student, carrying to the students something of the spirit of actual engineering work, I wrote several letters. On the whole, the best answer that I received was from a gentleman who is here to-day, who took up the idea with a good deal of interest and vigor. during the year he has fostered the Institute branch meetings in the institution with which he is connected as head of its electrical engineering department. I am interested to know what he thinks of it at the other end of the year. I am going to call on Professor Ryan of Cornell University to open the discussion.

Professor Harris J. Ryan:—I am more enthusiastic over the scheme that we have just heard of in the papers written by Mr. Rice than I was in the beginning, and in connection with my letter in which I expressed my enthusiasm to your President, I want, in speaking in behalf of the branch at Ithaca, those in charge of the work and our young men who are members of it, to express to the Institute our heartiest thanks for the kind courtesy shown in inaugurating this scheme and for what you have done for us. There we have, practically, the work of the local branch as a part of the regular work in electrical engineering instruction. It is not exactly required because we felt that in inaugurating the work there it was important that the work on the part of the individual student should remain his own choice as much as possible. However, attendance at the meetings and taking part in the work secure credit in lieu of required work in the regular course of electrical engineering instruction. Our plan is to abstract the papers, to present them before members of the senior class and certain members of the junior class that are well on with their work, together with all local members of the Institute resident at Ithaca; to abstract these papers and then interpret them to the students, using for this purpose the more able members of the senior class and graduate class assisted by the officers of instruction, and likewise with the assistance of the local resident members of the Institute. We supplement the work with biographical accounts, brief sketches, of the careers of the men who are the authors of the papers, so that the young men go forth with a little knowledge, at least, of the men who in electrical engineering matters are a power in our nation. When the reports of the discussions come, those are gone over, sometimes abstracted and in abstract form presented to the students, and sometimes *in toto*. The young men take great interest in the discussions, as well as in the papers, for the reason that the off-hand subject matter they can comprehend at once right then and there; and in this manner the effect and the results of this movement on the part of the

Institute, with us, have fully met the expectations of your president and the gentlemen who have inaugurated the scheme.

PRESIDENT SCOTT:—In connection with the local movement there is one gentleman who has a unique prominence, being at the head of two of the local organizations, one in a university (Purdue), the other in a city (St. Louis)—Professor Goldsborough.

PROFESSOR W. E. GOLDSBOROUGH:—As regards the local branch movements at Purdue and in St. Louis, I think they have both been quite successful during the past year.

When the year opened we had at Purdue an electrical society which had been in existence four or five years, we now no longer have a Purdue Electrical Society, but the Purdue Branch of the American Institute of Electrical Engineers, and this is the only electrical engineering organization at the university.

The meetings stimulate our young men, and bring them into touch with matters outside of the university in a way that is distinctly good. We have not given the boys any official credit at Purdue for the work which they have done in connection with the Institute meetings. That is, we do not recognize this activity as being a university exercise. It has been, with us, a means of stimulating the young men to make their own success of the meetings; and the members of the faculty take just as little part in the meetings as possible. We want to have the boys learn to do these things for themselves.

At St. Louis we have held meetings regularly every month, and to our secretary, Mr. Swope, I think the success of our work is due. If we can have a man devoting as much time and energy to the Institute meetings in each city as Mr. Swope does in St. Louis—and I doubt not other secretaries are quite as energetic—it will mean that in the course of a few years we will be having "New York meetings" everywhere, and it will be quite as much a treat for the New York members to have our discussions as for us to have the New York discussions.

PRESIDENT SCOTT:—I wish we had time to read the letters that Mr. Rice spoke of. There are quite a number of them, but it is hardly practicable to read them here. One of the good letters was from Mr. Junkersfeld, secretary of the Chicago organization.

PETER JUNKERSFELD:—As for our work in Chicago, as stated in the report, it is one of the oldest, if not the oldest, branch of the Institute. For several years the meetings, while they were held at fairly regular intervals, could not bring out a very large attendance, one reason being perhaps that there are two other engineering societies in Chicago.

One of the points that I think deserves perhaps a little more mention is the fact that an effort should be made to hold our meetings before the discussion is printed in the various electrical papers. We found in Chicago, where the meetings were usually held ten days after the New York meetings, that the

matter was just a little stale. The members had read all the New York discussion, and they felt that everything possible had been said; and I think if the papers were sent out promptly and meetings held before the discussion is published, the whole matter would be fresher and we would really get more local discussion and more local interest. That is a point that we feel in Chicago particularly.

Then there is a serious question, too, as to the influence of the other societies. The work has been going on harmoniously and all of them have very good meetings, but if we could combine our efforts, which we may be able to do at some time in the future, we think it would be very beneficial to the Institute.

PROFESSOR RYAN:—Speaking in behalf of the Ithaca branch, I would like very much to say that they would be heartily pleased to contribute to the expense of the maintenance of that branch. It certainly must cost quite a little to furnish us the large number of reprints of the papers as the Institute has during the past year. A large proportion of the class in the outset said that they would be perfectly willing to pay the regular price of the transactions in order to get those papers. Naturally, the matter was not taken up further when the papers came along without price.

PRESIDENT SCOTT:—I would like to ask Professor Ryan how the new student privileges meet the demands of these universities.

PROFESSOR RYAN:—I think that 60 to 75 per cent have not tried it yet, it was too late in the year. It probably will entirely meet the demand. That is my impression.

SECRETARY POPE:—I see that the branches call, as members have called and meetings have called, ever since I have been Secretary, for the earlier publications of the papers. With competent assistance at headquarters, and the use of the typesetting machine, and rapid processes of engraving, we practically rival the evening newspapers in getting out our edition of advance papers—when we get the copy. We have gone so far as to rewrite papers, but we have not yet originated them. When the actual authorship of papers is delegated to the Secretary's office perhaps we will be able to get them out a little earlier.

So far as the Secretary's office is concerned with branch meetings I feel that we have not really done justice to the work. We have a great many other things to attend to, and they all come along in a bunch, and it has grown on me during the last year that this was work for some one man to do, who was interested in it, and familiar with the requirements, and perhaps one of these local secretaries mentioned will develop some day into a general local secretary to take care of the branch business. Really, it has become sufficiently important, as we may see from the experience of the last year. Before they were fairly started, we began to see the end of the season, but we are now

in better shape, so that we can make an earlier and a better start next year; and if the interest keeps up, as there is every reason to believe it will, the branch movement will be a very important part of the work of the Institute, and you can see from what these gentlemen have said to-day that it is of importance to the future of the Institute. These young men coming up learn not only of the work of the members, but of the personality of the members themselves, their biographies, who they are. They come to our meetings, and they meet the older members face to face, and when they go out into the engineering world one of the first things they will find they require to qualify them is to become members of the Institute and coöperate with others in the general progress. Now, this is the work not only of the branches, but also of the student enrolment which has been inaugurated, and which, as you are probably aware, is limited to three years. No one can be enrolled as a Student for more than three years, after which time it is supposed he will become eligible and will become an Associate; and in the discussion, and in the formation of that enrolment, as we call it, of students, the whole object of that work is the future of the Institute. We have undertaken the work at a loss. It doesn't pay the expenses of carrying it on; but what we look for is the future development that will come from the enrolment of these students and the training them up in the way that they should go.

MONDAY.—EVENING SESSION.

PRESIDENT SCOTT:—In the American Institute of Electrical Engineers a large part of our work is the recording of what has been done, the getting together of data, the description of electrical work that has been accomplished, in order that we may know what has been done, and how new work should be done, as a basis for the future. We also extend out from the present and from what has been accomplished, to that which is to be accomplished along the same lines. For example, we have the electric railway accomplishing certain things now, but advancing on to new lines of activity, to higher speeds and heavier work.

Another department of work in which it is from time to time the privilege of the Institute to take part, is that in which we branch out into the new things, where scientific discovery of a new order in its application to useful ends brings to us a new kind of phenomena, a new kind of application, and it is to work in this field that we are to be treated with a presentation to-night. The carrying of electricity through gases and the illumination of gases, which a few years ago was simply a scientific experiment, is now brought into practical use through the experimenter and the engineer. It is our privilege this evening to have explained and demonstrated to us some of the latest developments in this line, which are giving

great promise for the future, as they deal with certain operations of lighting and current transformation which are of the greatest practical and commercial value.

The main presentation will be made by Dr. Von Recklinghausen who will be followed by Mr. P. H. Thomas, who will describe the apparatus. I have pleasure in introducing Dr. Von Recklinghausen.

DR. MAX VON RECKLINGHAUSEN:—Since the Hewitt lamp first was shown, at the Conversazione of the American Institute, two years ago, this type of lamp has aroused the greatest interest throughout the world. A steadily increasing number of electricians and physicists have stepped into this so intensely fascinating, newly opened, or, to be more exact, re-opened field of research. We may therefore expect a speedy development of the mercury lamp and its many-sided applications.

I thought it would be appropriate at this stage of the art to look back on the earlier work in this direction, particularly since the principle underlying the Hewitt lamp; that is, the passing of current through mercury vapor, is one of the very oldest ever applied for the generation of electric light, older, really, than our whole electrical industry.

As early as 1860 Professor Way of England demonstrated the enormous candle powers obtainable by using mercury vapor as a conductor of the electric current. He used for his lamp an apparatus having two reservoirs, both of them filled with mercury. Each reservoir was connected with one pole o the line. A little cock was opened on the upper reservoir, and mercury was allowed to flow through to the lower reservoir. The current going through that fine stream of mercury heated the stream and brought it to evaporation. The current formed, then, an arc between the nozzle of the upper reservoir and the surface of the lower reservoir. He seems to have tried this not only under atmospheric pressure but also in a vaccum. Way examined in detail the color of the mercury light obtained in this manner, and he remarked on the strange look of things and faces in the light. We have some extremely enthusiastic reports from that time in the newspapers as well as in the reports of Trinity House, the English Lighthouse Commission, on the enormous far-carrying candle power of the mercury vapor light obtained by this means. Had the current sources at that time been more commercial—they being primary batteries, of course—who knows whether the green-blue of the mercury lamp would not by this time have become indispensable to us? Whether we should not have become so used to this color of light as to call the color of faces exposed to it beautiful? After all, beauty is only a matter of custom.

Other problems, more important, came up in the electrical field, and the mercury lamp was entirely forgotten for a good many years. The first we hear about it is in a patent granted to

Rapieff in 1879. Rapieff used an inverted glass U, the two columns of which were filled with mercury. It was constructed about like this, (indicating)—the U was tilted over so as to allow the two mercury columns to connect; then the U was tilted up again, and after the metallic connection was broken, current went through the gas above the columns. In his patent he does not speak very fully of what the gas must be. He mentions mercury vapor. He says one can also apply a vacuum.

A patent by Rizet, of March 20, 1880, described a very similar U shaped lamp. Rizet proposed early to alter the green-blue color of the mercury vapor by having certain gases filling the space between the mercury electrodes. Amongst others, he proposes nitrogen, which gives a reddish discharge.

In 1887 Langhans obtained a patent for a U lamp practically the same as the one that Rapieff first made. How far those three men tried the lamps, it is hard to say. One thing is certain—they were not commercially successful.

The first really successful mercury lamp was made and described in 1892 by Arons, the German physicist. He made little U lamps very much in the same way as Rapieff describes them. (By the way, I do not think that he knew anything about Rapieff's patent or any of the earlier ones.) Those little U lamps were filled with mercury, and he makes a particular point that the air above the mercury must be exhausted very carefully. He found very soon that that was one of the most important things to observe for obtaining a good mercury light, to have an extremely good vacuum. The mercury vapor formed inside must be quite free from other gases. Arons goes into detail into the question of the color of the spectrum of the mercury. Furthermore, he determined the efficiency of the mercury arc obtained in this way and he found it to be far superior to any other artificial light source. He made rather exhaustive experiments to determine the influence of the length of the gas column on the voltage, and found the law to be fairly simple. Arons did not succeed in making a lamp that could be run with little ballast or no ballast resistance. His lamps had to be run with 40, 60, 70 and 80 per cent. ballast resistance if he wanted to keep them running at all. This, of course, spoiled the extremely high efficiency that the lamp has in itself, commercially, because so large a per cent. of the energy is absorbed in the ballast. Arons did not appreciate fully all the important influences governing the electrical characteristics, especially the conductivity of the vapor. He could make the lamps satisfactory only by absorbing in water the heat developed by the lamp. The lamps which were on the market for spectroscopic work were those U lamps, as described, in a box with running water. It is natural that such a lamp would not be satisfactory for illuminating purposes. One had first to understand clearly which were the factors governing the elec-

trical characteristics, especially the conductivity of the vapor, before one could begin to construct a serviceable lamp.

This is the point at which Cooper Hewitt stepped in. Hewitt's investigations in this direction are really pioneer work in the field of the mercury lamp and of vapor lamps generally; not only because he taught us how to make the most serviceable illuminating lamps, but also because his research in this line opened up entirely new applications of vapor electrical apparatus, the importance of which may be enormous for the advance of electrophysics and particularly for the advance of our electrical industry. What Hewitt has taught us in regard to the lamp proper may briefly be stated as follows: To obtain a lamp of the desired characteristic, the radiating power of the lamp must be correlated to the energy spent inside the lamp in such a way as to obtain inside, in the gas, the most favorable temperature or density conditions for the efficient generation of light. This controlling of the temperature and density inside the lamp is done by Hewitt in a properly rated condensing chamber outside the light-giving column. In the lamps shown here you see the bulbs are sealed on. The mercury condenses in those bulbs and keeps the density down to the desired point. It is extremely important—and Hewitt has done an enormous amount of work on that—to get the right ratio between the size of the condensing chamber and the size of the tube and the current which one wants to pass through the tube. I do not know whether you remember from the paper which Hewitt published some time ago, the strange characteristic curve of the Hewitt lamp. The curve looks something like this (indicating). If this axis represents the voltage, the horizontal axis represents the amperes. The characteristic voltage curve, with increasing amperes is something like this (indicating); then it rises steeper. The point at which we want the lamp to run is just before it bends up. This point (indicating) represents the most efficient temperature of the mercury vapor for the generation of light. If one runs it on the down part of the curve, the lamp is not so efficient as on the knee. If one runs it on the rising part of the curve the lamp becomes extremely inefficient. If one allows a rise of voltage up to, say, 50 per cent. of the normal voltage, the efficiency of the lamp, which is about .3 to .4 watts per candle, spherically, goes down to .8 or .9 watts per candle.

Hewitt has brought forward the importance of discriminating three capital points in respect to the conductivity of the electric currents in cases generally. The first point is, *positive electrode resistance;* second, *resistance of the gas current proper;* third, *the negative electrode resistance.* The last is the most important. In the ordinary vacuum tubes, such as Geisler tubes and similar apparatus, we find that they have an extremely high resistance. This is due, practically, entirely to the extremely high resistance of the negative electrode. If we want to give them a low resistance we must have absolutely a negative electrode of low

resistance. Such a low negative electrode resistance is obtainable, according to Hewitt's definition, by using an electrode which the current keeps in disintegrating, boiling or similarly changing condition. Therefore, if we want to make a lamp with low resistance we have to put in, as negative electrode, a disintegrating electrode. We can bring such an electrode to disintegration either by connecting it with the positive and separating it after that, or else by forcing a high potential through it. A high potential of several thousand volts will break through, make the electrode disintegrating, and then the low line potential, which may be attached to this electrode, will follow. Mercury itself is the best material to be used for such disintegrating electrode, because the mercury which disintegrates steams away from the surface, condenses again on the walls of the tube, runs back to the negative, and the negative is again like a new one. Physically expressed, we see that the mercuy has an extremely high starting but a very low running potential. The starting potential, the break-through potential, I may call it, for the mercury, is a good many thousand volts, perhaps 6,000 to 8,000, in some cases 15,000 or 30,000 volts, whilst the running potential, that is, the drop across the electrode in a burning lamp, like one of these, is only about five. Once the lamp has been made conductive by means of the break-through of the dielectric on the surface of the negative—that means, when one has brought the negative to a disintegrating state, the lamp conducts extremely well. As soon as the current is interrupted, in the fraction of a second, perhaps the hundred-thousandth of a second, the conductivity of this lamp will cease. If you put the lamp out, and right after doing so put the line potential on again, the lamp will not start again. I can be as quick as I like in making the connection again, you will not see the lamp start. We have first to break through the negative electrode resistance and make the negative electrode disintegrating to get the lamp to run.

On the fact that such a mercury electrode has a very high discharge and a very low running potential, and, furthermore, on the fact that the lamp loses its conductivity practically right away after the current has stopped passing through, Hewitt has based the application of the lamp as a breaker for high frequency work. You may perhaps remember from the publications that he has applied a lamp shaped something like that large bulb with two electrodes for generating high frequency, for, say, wireless telegraphy or similar applications.

If we start the current in the lamp by making the electrode disintegrating, we will naturally believe that the current will go through such a disintegrating electrode only in one way. The disintegrating electrode has to be negative. We may say, although that is not usual, that a current will go from that disintegrating electrode in the tube up to the positive. What we can do with such a lamp, which allows the current to go

through only in one way, Mr. Thomas will describe later on to you. It is natural, if you put an alternating current on the two electrodes of one of those lamps, that you have to put on a very high potential to get the first phase through. Now, as soon as that phase is through, the lamp has to be started in the other direction. That means putting a high potential on again. Then that phase is over and the next phase comes again; we will have to start again by means of a high potential, and so on. That will mean practically running the lamp at all times on a very high starting potential to get three amperes through, as we have here. On one of those lamps with alternating current we will have to apply perhaps 5,000 or 6,000 volts, while here these lamps are running on 120 direct current.

A few more words about the Hewitt lamp itself and its different applications. I may start by giving just a brief description of the lamp. The lamp consists of glass tubes to which is sealed the condensing chamber. Into the glass tube we lead the current through platinum wires sealed into the tube. As positive we use either another mercury puddle or any other metal, like iron, copper or similar material. The temperature of the lamp outside is not very high, just about like that of an over-running incandescent lamp. For starting we use this kind of apparatus (indicating). We have our 120-volt direct current coming in here. One line goes through two coils, with about 2,000 turns on an iron wire core. From that coil the line goes through those two little regulating resistances to the lamp. The other pole goes directly to the lamp. The lamp itself can be short-circuited by means of a small resistance, and this switch (indicating), which is a very fast break under oil. If we put the line potential on this starter nothing happens. If we press this handle down the current flows through those coils. You can see that when I open this switch (indicating)—now, the current flows through here and magnetizes those coils. As soon as I let go, a very fast trigger break occurs in here under oil, and in what way the high potential generated starts the lamp. With this arrangement we can get very high potentials, five and more thousands of volts. We can run two lamps in series on double voltage, or more lamps on a fitting voltage. If we want to make 50-volt lamps, we make them about half as long as the 100-volt lamps. If we want to make lamps for small current we take a smaller diameter. The tubes can be bent in any shape, U shape or otherwise, as long as it is not too much trouble for the glass blower—and those troubles begin very soon.

When we started to work on the Hewitt lamp we had great hopes regarding its application for different purposes, and I must say that our hopes have been fully realized. The lamp is extremely actinic. That is, it is very rich in photographic active rays, and the Hewitt lamp has proved itself to be an extremely useful and reliable illuminant for the photographic trade. People have for some time used this lamp successfully

using only the low current of three amperes, where they formerly had to use a high current, such as 25 to 50 amperes, with arc lamps, and they get better results with this because the light is so evenly distributed all over the tube. This, of course, refers mainly to its use by photo-engravers and people who do printing, such as blue printing or portrait printing. But the light is also an excellent equivalent for daylight according to the opinion of the best photographic experts. Some of the best photographers in New York have taken pictures by the light of three or four or five lamps, and they say they cannot detect the slightest difference as against pictures taken by daylight, and, of course, they appreciate the advantage of having the lamp always handy, whereas the light they get from outside is not always there when they want it.

Another application is in the hands of physicians, who have taken a great interest in the lamp and are making many experiments, as they expect great healing effects on certain diseases from the actinic rays which are sent out by the lamp. The lamp practically lacks red rays, by reason of which physicians find they can discriminate between certain kinds of inflammations very much better than by daylight, which is so rich in red rays.

The most gratifying for us is the fulfilment of our hopes regarding the lamp as a light source for general illumination where it is important to get the cheapest possible light, where the true ratio of color values is not of importance. We knew, and find it confirmed daily by users, that the total absence of the red rays gives a light which does not fatigue the eye. We also have made actual experiments (although I must say the measurements are only qualitatively reliable), which have shown a distinct superiority of this light which does not have any red rays, over any other illuminant as to the fatigue it produces upon the eye. It is, therefore, a splendid illuminant for places where fine mechanical work, fine jeweler's work, or reading, writing, and especially draughting, is done. We think, therefore, we are justified in saying that the Hewitt light may be of the greatest benefit to mankind.

PRESIDENT SCOTT:—A very notable occasion in the history of the Institute was two years ago this last spring when a conversazione was held at Columbia University in New York. At that time, I believe, was given before this Institute the first public exhibition of the light which we have before us to-night. Mr. Thomas will now give us an exhibition for the first time in public and an explanation of a single-phase vapor lamp. He will also give the first public exhibition of an alternating current vapor circuit breaker.

I have the pleasure of introducing Mr. P. H. Thomas.

MR. THOMAS:—Dr. Von Recklinghausen has given you a full description of the Hewitt mercury vapor lamp burning upon direct current, and has described the principles

upon which its operation depends. I think most people are in the habit of looking at this invention of Mr. Hewitt's as a new method of getting light. I would like to revise this view. What Mr. Hewitt has really done is to study out the phenomena involved in this manner of getting electricity through a vacuum. It is not a lamp, except incidentally. It is really a new group of phenomena, a new branch of physics, almost. I do not mean to say that he first observed the phenomena, but he is the first man who has worked them out in such a way that they can have commercial applications.

Looking at the operation of the lamp as an experiment in physics we find a number of very curious phenomena developed. Dr. Von Recklinghausen has spoken of most of them Looking at it as a means of doing useful work, we see a number of interesting applications.

The first application to be developed commercially is the direct current lamp. The second, which is now being developed, is the vapor converter, shown so far only as a three-phase converter. The third is the vapor interrupter, or more properly, the vapor discharge gap, and, in addition there are some new applications to be shown to-night.

Perhaps I had better summarize again the peculiar characteristics of this apparatus of Mr. Hewitt's. Strictly, Mr. Hewitt's work has been the study of the phenomena and the laws governing the passage of electricity at low voltage through a high vacuum. As has been already explained, to accomplish this result commercially and operate with low voltages, it is necessary to use for the negative electrode some electrode material like mercury, something which is easily disintegrating, if you please, and also reconstructing. The most striking phenomena of all is the behavior of the negative electrode resistance. Nothing like it, as far as I know, is found anywhere else. At first, if you attempt to pass a current through the lamp, you meet with very great resistance or reluctance located at the negative electrode. Once you start the current by overcoming this reluctance, as can be done in a number of ways, which will be taken up later, it continues to flow with a loss of voltage perhaps as low as 10 volts, until the current is interrupted or reversed. This abrupt reduction of reluctance is remarkable, perhaps from 30,000 volts to 10 volts in extreme cases. Strangely, the positive electrode, which by convention is taken to be supplying the current, has very little electrode resistance or reluctance. The positive has, apparently, no reluctance to starting and causes little loss of voltage when running. The two electrodes taken together cause from 11 to 15 volts or more loss when running, according to conditions. These running losses are very hard to apportion between positive and negative electrodes. In addition to the two electrode losses, we have in the lamp the resistance of the vapor. This is an extremely complex phenomenon, and nobody, except Mr.

Hewitt, as far as I know, has had any clue at all to the laws governing it; but he has successfully worked out practically all the conditions, at least as far as the range of conditions bearing on his lamp is concerned. This vapor resistance is a most peculiar thing. I will not attempt to state the laws governing it; this would take a whole paper in itself. I will state, however, that in the lamp the principal part of the total voltage is taken up in the vapor column. This is the light-giving portion of the lamp, and for high efficiency it should, of course, consume a large part of the energy. In the vapor converter the light plays no important part, and the vapor path is purposely made very short and very wide, so that little or no voltage is lost there. Therefore, a vapor converter may be made to run with from 10 to 15 volts total loss. A peculiar thing about these negative electrodes and positive electrode resistances is the fact that, other conditions being unaltered, they are practically independent of current. One hundred and fifty amperes will give the same voltage loss as three or four amperes. I must qualify this statement with one exception. If the current drops below three amperes or so this voltage loss does not fall, as perhaps you would expect, but rises very rapidly, and rises to a very high value, sometimes to several hundred volts at .1 ampere.

For the purpose of clearness and definiteness the general type of apparatus under discussion is spoken of as a "vapor conductor," that is a device which carries current by means of mercury or other vapor. The lamp is spoken of as a "vapor lamp"; the converter, as a "vapor converter," and the circuit breaker, of which I am to speak later, as the "vapor circuit-breaker." This nomenclature will distinguish the various applications from one another and from other types of apparatus performing the same function.

Next, I will describe briefly the operation of the three-phase converter for the benefit of those who may not perhaps understand it. Then I will describe and operate a single-phase vapor converter, a single-phase alternating current vapor lamp and an alternating current vapor circuit breaker.

The principle underlying the three-phase converter, as already stated, is this negative electrode resistance. As Dr. Von Recklinghausen has told you, if you attempt to pass alternating current through an exhausted globe with electrodes or any vapor conductor, after applying the necessary means to start it, the current will continue to flow for one alternation, and then, as it becomes zero preparatory to reversing, this electrode resistance is formed again and everything stops. But suppose we take three transformers, or three sources of potential connected in star with a three-phase relation, as shown in figure 1; suppose we connect the neutral point to the negative electrode marked D in this figure, and each of the three free ends of the transformers to the other three electrodes which are positive. On account of the three-phase relation, it is evident that at all times one of those three positive electrodes, A, B, or C, will be

positive with regard to the negative electrode D. Suppose now, by the application of high potential or other suitable means, we start the current flowing at any time, we will say, for instance, when the electrode A is positive. A immediately starts to supply current to the negative electrode D, which current passes around backward through any load we may choose to put on the apparatus, to the neutral point of the transformer. As the voltage begins to drop off this current tends to drop off, and if there were no other electrodes would soon become zero; but on account of the three-phase relation the electrode B reaches a positive voltage before the electrode A loses its positive

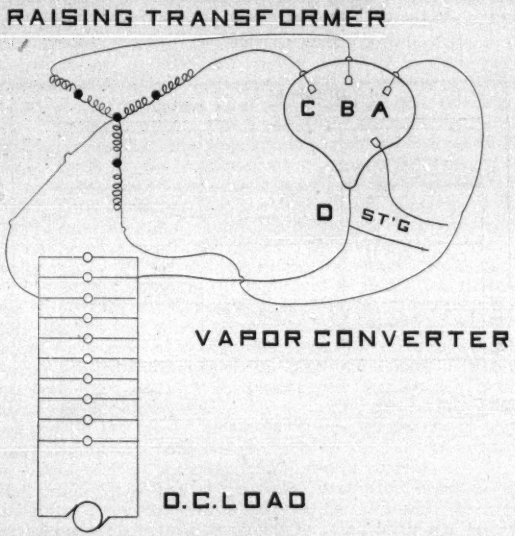

FIG. 1.

voltage. As a result, current will start to flow from B before it ceases to flow from A. Consequently the electrode D, the negative, at no time ceases to pass current. Similarly, as the electrode B begins to experience a falling voltage, the electrode C has a positive voltage again and takes up the current. By the time C is losing its positive e.m.f., A has gone through the negative cycle and has again become positive and will in its turn take up the current a second time, and so on indefinitely; and this apparatus works just as simply as described. If, however, at any time you open the circuit leading to either A, B or C, the converter will stop. This experiment has been shown a number of times.

When operating as described, the loss of voltage on the useful current, that is the loss of voltage between the negative electrode D and the particular positive electrode which is supplying current, will be 10 to 14 volts. The voltage between D and the other positive electrodes will be very much higher but negative, and as they are supplying no current there is no loss of energy. To explain a little further, consider figure 2. The full lines are supposed to represent the three-phase alternating e.m.f's. You see they differ by 120 degrees. As already explained, each one of the positive electrodes, A, B and C, carries the current for one-third of the period. We will say, during the first period, that the electrode A is carrying the current. At the time the voltage of transformer A is impressed

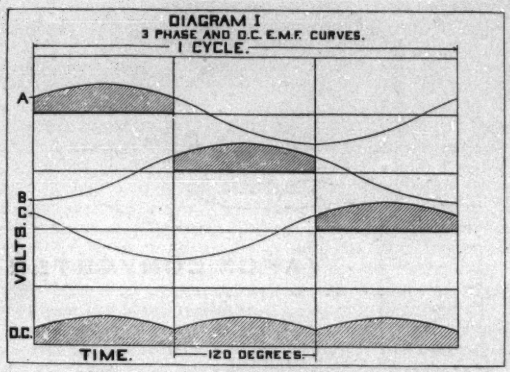

FIG. 2.

between the neutral point of the transformers and the electrode within the chamber. It is divided into two parts; one part of, say, 14 or 15 volts in the converter, and the rest upon the load. That is to say, if we subtract in the figure the portion between the lines for the loss in the converter, we have the shaded portion representing the voltage which is impressed upon the load. Similarly during the second third of the period we have the energy supplied by B, the second positive electrode, and similarly a slight loss, and the remaining voltage, shaded, representing the voltage impressed upon the load; and for the third portion of the period, we have C supplying the voltage. As a result we have the lower shaded portion of the figure as the voltage impressed upon the load. This, as you see, is slightly

wavy, slightly varying. If the load itself contained a large, or even a considerable amount of inductance, this waviness would nearly all disappear. For the sake of clearness I have had drawn in Fig. 3 the e.m.f. curve resulting in a non-inductive load circuit from vapor converters of different numbers of phases. Of course, it is evident that if the three-phase converter will operate as shown, a four-phase converter will operate similarly, or a five or six, or any convereter with a large number of phase. Going down one, however, if we attempt to run what I have marked as a two-phase converter, we get into difficulty. I must explain the use of the term two-phase. It is not two-phase in the sense in which the word is usually employed. Two-phase usually means quarter-phase; it means two e.m.f's 90 degrees apart. Strictly we ought to speak of two-phase as two opposite phases; at least, we should speak of it that way in connection with vapor converters. So we must understand that two-phase means two e.m.f's exactly opposite, 180 degrees apart. If we attempt to run a converter from such a circuit, according to its law, the negative electrode resistance will re-establish itself at the common zero point of the waves and stop the operation of the converter. This result is confirmed by trial. But assuming that the current will continue to flow, we would have an e.m.f. on the direct current circuit something like what is shown in this figure. Of course, there must be 14 volts subtracted for the loss in the converter. In the figure the "ratios" are the ratio of minimum to maximum ordinates of the direct current voltage. It is .5 in the three-phase converter. In the four-phase converter .7 and four phases can be obtained from any of the common two-phase circuits, so-called, by using proper transformers, by reversing phases. In a six-phase converter .86 and six phases can readily be obtained from any three-phase circuit by suitable transformers. Any inductance in the circuit will tend to smooth out these waves. For any commercial purposes probably four or six-phase current is as satisfactory as perfectly steady direct current.

The principle of the single-phase converter depends upon keeping the converter "alive" during the two periods in each cycle during which a converter constructed after the principle of the three-phase converter but with two positives only would go out—by causing the current from either positive to lag behind its e.m.f. until the e.m.f. on the other positive should itself be able to support current. This is easily accomplished by passing the whole or a part of the current through an inductance. Refer to Fig. 3 and suppose one electrode is during its half of the cycle supplying current to an inductive load. The current will build up a little behind the e.m.f. on one positive, and when the time in the alternation comes for the latter to fall off will lag behind this e.m.f. But you notice that before that current gets to zero we have a positive e.m.f. on the other positive terminal. The result is that there is no instant during which current is

not passing through the negative electrode, so the negative electrode never gets a chance to resume its resistance. As all loads are not inductive, to use this converter on any kind of load an inductive resistance may be put in shunt with the regular load. This shunt circuit will take a certain amount of what you might call leakage current through the negative electrode, keeping it alive at all times, but when, however, much other load is thrown on, there will be no difficulty in taking power from the main circuit.

There are three usual methods of starting lamps and converters. First, as Dr. Von Recklinghausen has shown you, the standard commercial starting outfit for the lamp makes use of a high potential from an induction coil, momentarily applied

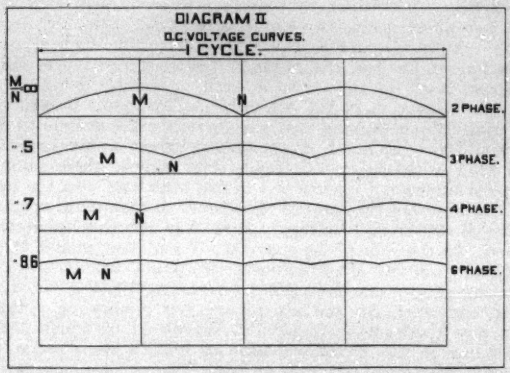

FIG. 3.

to a starting band and to the positive electrode. This high potential is obtained by a quick-break switch. The method can be used to start the vapor converter, but there is one inconvenience about it. The converter runs on alternating current, and the quick-break switch may happen to break the alternating current when it is pretty nearly zero, or it may break it near the maximum, and it is necessary to try a number of times before you hit the wave at the proper point for causing a rise in the potential.

Secondly, the converter may be started by means of a high-tension transformer. If this transformer be excited from the same supply as the converter, the phases of e.m.f. from transformer and converter will keep together, and the e.m.f. will

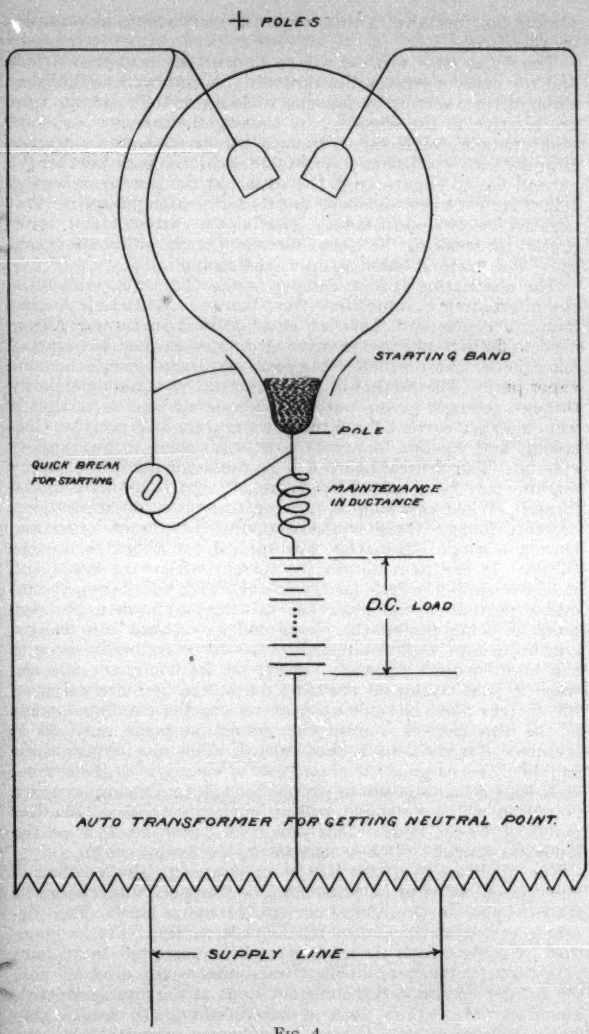
+ POLES
STARTING BAND
POLE
QUICK BREAK FOR STARTING
MAINTENANCE INDUCTANCE
D.C. LOAD
AUTO TRANSFORMER FOR GETTING NEUTRAL POINT.
SUPPLY LINE

FIG. 4.

always be applied at a time when the converter is able to pick up the current.

Thirdly, another method will be shown, the one used by Arons, and for many purposes the simplest. A current is established through the vacuum by forming a closed metallic circuit from the positive to the negative, by causing the mercury or some other metallic conductor to connect the positive and negative. If under such conditions this metallic circuit be opened so that the current has to pass through the vapor; at the instant of separation there is caused somehow or other a breaking down of that negative electrode resistance. That is, the current is not interrupted by breaking the closed metallic circuit within the vacuum. This method eliminates the high potential.

The alternating current lamp is really the same problem as the alternating current converter; but the alternating current lamp, of course, will have no external load to carry. All we need to do is to use two positive electrodes, instead of one, and allow the current from both those positives to pass through the same vapor path. The result will be a direct current passing steadily through the light-giving portion of the lamp, just as though it were a direct current lamp, only we require two positive electrodes, and we also require the neutral point of the supply system. That neutral point, if it be not available in the supply circuit, may be obtained by means of a small auxiliary transformer. When this lamp is running there is a pulsating direct current, though there is not actually very much pulsation. During a single alternation the applied e.m.f. has to do two things. It has to maintain the current within the lamp, and it has to supply a little energy in the choke coil during the increase portion of the pulsation. At the time when the zero point is being passed the choke coil gives back this energy, which during the next alternation has to be restored. Now, if the lamp operate normally, nearly at its minimum voltage, when it is to be started, the lamp during the first alternation of the current must be built up from zero to the maximum point of the variation—not from the minimum point only, as is required after the lamp is once started. This may require three or four times as great an absorption of energy in a given time. It is thus advantageous to supply for the time being an extra potential, which we might call an auxiliary or supplementary potential, to the lamp. This should be discontinued when the lamp has started. This is done in the a.c. lamps shown.

The application of the Hewitt apparatus to the breaking of alternating currents is quite simple. Suppose an attempt is made to pass an alternating current through a lamp The current goes out at the end of the first alternation. But suppose that by some means the current to be interrupted be made to pass through the lamp. Then when the means used to pass the current be removed the current stops at the first zero point. There are two or three ways of accomplishing this result. One means consists in establishing a mechanical circuit within the

vacuum; to carry the current, and then when desired break the mechanical circuit, and the current will go out at the end of the first subsequent alternation, at which time there is no stored magnetic energy and no chance of a rise of potential. A small mercury switch, acting on the principle described, is here shown. It is used to cut out the a. c. lamp. The switch is so constructed that tipping in one direction connects the mercury in the electrodes and tipping in the other separates them, which operation interrupts an alternating current.

This type of circuit breaker has two or three advantages aside from its ability to open circuits. The first is that the contacts are practically perfect, if mercury be used. In the second place, the contacts will not deteriorate, they will not burn. They do not have to be replaced or carefully adjusted. In the third place, on account of the very short distance which the current needs to be carried in the breaker, it is easy to get a large cross section of conductor. This makes a very light apparatus, which can consequently be very easily controlled electrically or mechanically or in any other manner. This type has two principal disadvantages: the vacuum must be maintained, and mercury is rather objectionable; but these disadvantages are insignificant in comparison with the advantages to be gained.

Dr. Von Recklinghausen and I have shown to-night a number of the applications of this Hewitt apparatus, and have tried to give you some idea of the physical meaning of it. It is a fascinating field, and I trust you will hear again from Mr. Hewitt's inventions before we are through with them.

PRESIDENT SCOTT:—As I have been listening to Mr. Thomas discussing the single-phase relations I have wanted to get my ideas into some form of analogy, into some way of ordinary thinking or acting. I presume Dr. Franklin may have in his mind certain differential equations which give him a perfectly clear idea of just what is going on. I used to have an apparatus that I worked with, and worked with very hard, and it throws some light, to my mind, on this single-phase problem. It was a bicycle. My first bicycle weighed 57 pounds, and on the Pittsburg hills it made a very profound impression, that I remember to this day. This bicycle, of course, was a piece of single-phase apparatus. One pedal went down while the other was coming up—down and up; pullee, pushee; no, it was all pushee, no pullee. (Laughter.) Now, in that respect, as there was no pullee to it, it was like the resistance of the negative electrode. I had to do all the work in one direction, only one end of this single-phase system worked at one time, and the other end at the other time; and as I used to go up hill, my 57 pounds going up grades of 15 per cent. or a little less, I used to go very slowly, and I found it very hard work to get over the dead point. Now, Mr. Thomas' current has a very similar trouble—it cannot get over the dead point; and I imagine this evening that if I had had a little apparatus similar to what he has, and could have gotten a little spring under my pedals, something that when

I pushed my foot down as far as I could, would throw it a little farther until I got my other foot just over that dead point, I could have got my wheel over the hills in the same way in which he makes his lamp go. So that I think my experience with the bicycle has helped me to clear up in my mind the difficulty and the ingenious method of overcoming it which are found in the single-phase lamp and the single-phase converter.

Q. (A MEMBER) I should like to ask whether the efficiency of the converter is measured solely by the ratio of 14 to the volts lost to the converter.

A. (MR. THOMAS) That is all the loss there is, except what may occur in the auxiliary apparatus. For instance, if you have an induction coil to keep it alive, that will take a certain amount of energy. There is simply a flood-gate opening, you might say, to allow the current to go out. I ought to have called attention to one thing that inadvertently slipped my mind, in which respect this converter has a great advantage over ordinary converters—the matter of regulation. This 14 volt loss is constant in current. That is, the thing is practically perfect as far as regulation goes. There is really no lost energy there which affects the efficiency.

DR. VON RECKLINGHAUSEN:—On a 120 volt circuit, I have had an over-voltage of 135 volts. That makes the temperature of the lamp run up, and that alters the radiation and the conductivity. The way the lamps are made now they will stand very nicely about 5 or 10 per cent. variation either way; but if it gets up to 15 and 16, something like that, they won't do it. The mercury gets too hot and then we work on the up-going part of the volt-ampere curve. The conductivity of the vapor goes down, the resistance goes up and the lamp has to cool down again before it has its normal conductivity.

Q. Does it go out?

A. It goes out, yes.

Q. It doesn't get brighter then with high voltage?

A. Oh, yes, it gets brighter up to a certain temperature, but getting brighter means also getting hotter. It stands a certain amount, but not over much, just on account of that peculiar volt-ampere characteristic. If the voltage goes down the current drops down some, and if it drops down too much the current goes below the maintaining current. The lamps of this type cannot be run below, well, say, about 1.2 amperes, something like that. The normal amount is three amperes. Apparently there is a certain amount of current necessary to keep the electrode disintegrating. Once that current drops too low down, the negative electrode refuses to disintegrate any more and the current stops flowing.

Q. What voltage does that correspond to, 1.2?

A. On a 120 volt, lamp like this it may correspond to 80 or 90 volts line pressure.

Q. That is considerable of a drop?

A. Oh, yes. That is a drop which will never happen on a commercial line, according to what the central station people say.

Q. For a smaller ampere lamp you use a smaller tube?

A. Yes.

Q. What is the smallest ampere lamp you can make?

A. We have made what I may call toys for about .4 ampere or .3 ampere. They were for about a 100 volt circuit, They were about 70 c.p. They are too small to be made practically. We made a very nice lamp about half the size of this, but below that they are not of advantage. There is no advantage in going too low down.

Q. I would like to ask Dr. Von Recklinghausen whether I understood him rightly in the early part of the evening when he said that this lamp would not operate with a trace of any other gas in it.

A. Of course the lamp will stand a trace; that is certain. As a matter of fact, I suppose with the best apparatus at our disposal we will never be able to get out all of the gas; but if we have what I would call more than a trace—it is very hard to determine how much will spoil it—the lamp is of extremely high voltage and is unsatisfactory in every way. It runs very unsatisfactorily, blackens the glass and does all sorts of harm.

Q. Didn't you say you tried to add red to the lamps?

A. Yes, we tried that too. I mentioned in connection with one of the very early patents, mercury lamps in which the inventor proposed to use nitrogen to get a different color.

Q. That was never a commercial success?

A. Oh, no. The colors changed all right; there is no doubt about that.

Q. Would a red reflector give the light a red color?

A. The spectrum has no red, and therefore red glass or a red reflector would act like a gray or black glass or reflector; that means, no reflector. The only possible way of getting red from a source which has no red is fluorescence. I am sorry I did not bring that along. We have made some experiments to get dye stuffs which show fluorescence under the influence of certain mercury light waves; that is, which transform certain waves that the mercury light has into red waves. Rhodamin is one of those dye stuffs. If we have a piece of silk round the lamp, then the lamp looks distinctly red and people look a good deal more human than they do without it.

Q. It is very essential that the mercury should be very pure, is it not?

A. So long as the mercury does not contain gas it does not matter. We can use amalgams, but there are all sorts of troubles coming in—attack of the glass and that sort of thing; and then it is extermely difficult to get the gas out of an amalgam.

Q. This question is asked, whether the life is like that of incandescent lamps, say, 800 hours.

A. Well, without promising in every case, we can say that the lamps will surely live a thousand hours. Since we have really known how to make them; that is, since we know every trick of the new trade, practically no lamp has given out at all under 2000

hours. The candle power seems to drop slightly, due to a slight coloring of the glass. It will drop the candle power 10 per cent. or so. The life seems to be terminated by the vacuum getting bad. There must be some place where the air does leak into the lamp. It is highly improbable that it leaks in through the glass. In all probability it goes lengthwise through the platinum wire that is sealed into the glass. The lamp is put on to the pump again, pumped out, and is then like a new lamp. There is no consumption of the mercury. The mercury and the vapor is en irely enclosed, and the mercury electrode reconstructs itself all the time.

Q. Is the amount of light even all over the tube after it has been burning a few hundred hours?

A. Yes, it seems to be absolutely even all over I may say, speaking of candle power—it is of course an extremely hard thing to determine the candle power of a light the color of which is so very different from any of our yellowish standards. All our standards have a very yellowish color. Our photometer measurements I should not call more exact than within 10 per cent. Of course, we check them up with reading tests with standardized incandescent lamps, but still there is a good deal of doubt about them. The candle power of one of these is about 700 c.p. The ballast resistance is those two coils and those two little regulating rheostats. It is necessary to have it with this type of lamp. If we arrange the condensing chamber and the amperes of the lamp differently, then we can use less ballast; but we run into difficulties of a different kind, as to variation of pressure and so on. We have made lamps with about half the present ballast resistances, but they were not quite as satisfactory in other ways. The whole problem of the condensing chamber, the density and those things, is an extremely difficult one. The lowest voltage for which a lamp can be constructed would be the voltage of the converter; that would be 15 volts. That would be a lamp that gave no light; and any volts in excess would give a corresponding amount of light. If you make a 20-volt lamp, for instance, the 15 volts would be consumed in the electrodes and not give any light, and the five volts remaining would give light; of course this would not be efficient. The longer we make the lamps the more efficient they get, because the energy absorbed in the electrodes becomes a smaller percentage with high voltages than with low voltage lamps. The current at the beginning is somewhat higher than afterwards. I should say that a lamp of this type will take perhaps 4½ or five amperes for a few seconds, and to gradually work down to three amperes in five or ten seconds. For each lamp or each series of lamps we have a separate starting device. For instance, if we had 240 volts, we would have two lamps in series on one starting device. We have 15 volts in the electrodes, and about 20 volts in the ballast; that makes 35 out of 120. I should say 65 per cent. gives light and the rest does electrode work or ballast work.

Q. I would like to ask a question about this peculiar characteristic curve. As I understand it one voltage will correspond to two amperages. If certain voltage is impressed on the lamp, what determines whether the higher or the lower current flows through?

A. The lamp will go to the low ampere 90-volt point if we do not allow enough current to pass through it. It will go to the high current 90-volt point if we allow enough current to pass through it.

Q. But if the moment that the high tension is taken off is the moment you put on the current, will it simply go to the high current part of the curve?

A. That depends entirely on the ballast resistance you have. If your ballast resistance allows too many amperes, say the necessary four amperes or so, to pass through, then it will naturally go to the high ampere 90-volt point. If you allow only one ampere to go through, it will go to the low ampere 90-volt point; and wherever it goes on that inner upper end of the curve, it is in a very unstable state; the lamp is always very near going out.

There are some other phenomena connected with the lamp which we could not speak about to-night, because they are pretty hard to demonstrate with the apparatus we have here. For instance, just at the negative electrode there is a long pinkish flame shooting off from the surface, absolutely independent of the real light giving gas column; that flame in a properly constructed lamp may be two or three feet long, and has very peculiar properties under the influence of a magnet and so on.

Q. Well, I am reminded in that connection of that theory of Drude's that the escape of electricity from metal is due to the ironization of the metal and the giving off of a vapor consisting of iron. If that is true, there must be some sort of a cathode ray effect; and you say you have not detected any sort of a cathode ray?

A. It may be cathode ray effect, but in the way one detects cathode rays we have never detected or found any.

MR. C. O. MAILLOUX:—I would like to ask Mr. Thomas some questions regarding the commercial possibilities of the vapor converter. I would like to know, for instance, what is the largest that has been made thus far, and whether, in case a large output were required, it would be possible to group these little glass balls in various ways, so as to obtain a large resultant total effect. In other words, may we look forward to a time, in the near future, when we can operate a vapor converter giving the same effect as the ordinary rotary converter, of several hundreds, perhaps several thousands, kilowatt capacity? I also would like some idea of the possible cost, I should perhaps say the great drop in cost, that would result from the introduction of this wonderful invention. I may say we are all prepared to expect that the cost per k.w. will be very low.

MR. THOMAS.—There are very good prospects that in the end the improved vapor converter can be used for railway work. Of course, you cannot get any converters for that purpose now. Mr. Westinghouse is having the matter taken up in a very broad manner, with a view of ultimate speed rather than immediate results; and the different phenomena involved, the different problems, of which you can see there are a great many, are being investigated separately and individually and no effort has been made to assemble a single converter of the maximum capacity. The total k.w. that can be obtained from a vapor converter of this type is determined by the current that can be transmitted without undue heating and the generator voltage that is used. which voltage is determined by other considerations than the requirements of the converter itself. The converter within limits is not affected by the generator voltage. It is expected that they will be operated in groups if necessary, but there is good reason to hope it will not be necessary to group them.

Q. Suppose, due to some cause or other, the current were increased to 200 instead of 100 amperes, what would be the result?

A. I can illustrate. By accident here I just now crossed the two positive electrodes when I was starting the experiment. Nothing happened except the blowing of two small fuses. There was a dead short circuit through those fuses. You didn't know that anything had happened. If there were no fuses, the result would depend upon how the converter is designed. Nothing peculiar happens, unless the short circuit be very excessive. It doesn't affect the vapor injuriously. The chief difficulty is where the metal leads in through the glass. If the metal expands enough it will crack the glass. It is possible theoretically to change direct to alternating current in a small way. It may be possible ultimately in a large way, but we have nothing to say on that point. It is an interesting thing to speculate on. Well, to take this particular converter, as it stands, the difficulty limiting the capacity would be the heating up of the globe. If you put it under oil we might heat the platinum at the bottom so much that it would swell and break the glass at the seal. If you dissipate the heat the capacity of the device goes on up. There is no one limiting factor that we have found so far. The heating is proportional to the current, not to the square of the current. This gives the advantage that there is no variation of voltage due to change of current—therefore the regulation is perfect.

Q. With a fluctuating load will the device operate successfully or will the phenomena of a rise of resistance from overload, as seen in the lamp, cause trouble?

A. Well, the conditions between lamp and converter are very different. The lamp is designed to run taking all the voltage of the circuit. The converter only takes a small fraction of the voltage of the circuit, and you have all the remaining voltage forcing the current through in case of temporary excess of demand.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

HIGH SPEED ELECTRIC RAILWAY PROBLEMS.

BY A. H. ARMSTRONG.

Among the many questions to be considered in a new railway project, perhaps the one of primary importance is the question of the proper speed at which to *operate*, as depending upon this factor is not only the first cost of the road, but its cost of operation and probable receipts. It is the purpose of this paper to touch briefly upon some of the fundamental relations existing between first cost of a railway system, its probable cost of operation and schedule speed, discussing also the probable traffic receipts to be secured with different methods of operation. In considering so broad a problem in a paper of this length, it will be necessary to omit detailed proof of many of the statements made, but the method of arriving at the conclusions will be outlined. Most of the data presented is obtained from a very elaborate series of experimental tests, so that the results obtained may be considered of direct practical application.

Owing to the wide field covered by the electric railway motor, it is not possible to consider all classes of railways and therefore this discussion is limited to the relatively high-speed roads. It is a mistaken idea that acceleration problems are met with only in city or elevated work where the stops are frequent. Although the so-called high-speed roads stop at comparatively infrequent intervals, the relation existing between stops and schedule speeds often calls for the most serious consideration of fractional speed running of the motors. Such roads really act as tributaries to large city street railway systems and must be able to operate over several miles of city tracks at slow schedule and with fre-

quent stops, and also be adapted for operation at 40 or 50 m.p.h., with infrequent stops on a private right of way.

While each road presents its own local characteristics they can generally be divided into two broad classes, those having frequent stops and those having very few stops. Both classes of service will probably parallel one or more steam lines and must make a schedule speed that will compare favorably with that obtaining on the competing steam road. This high schedule speed must also be made with more frequent stops than given by the steam service, and in nearly all cases over a track which has many sharp curves, which have the effect of still further increasing the number of stops. Interurban roads having very infrequent stops, say one stop in five or ten miles, private right of way, and an alignment free from curves of less than three degrees, can give a service equal or superior to any competing steam line, and can furthermore provide the frequent service which has proved one of the valuable assets of electric roads. Moreover, the generating station, feeder system, motor capacity, and power consumption will be moderate in first cost. The problem of high-speed electric service therefore is comparatively simple, provided the alignment is free from sharp curves and the stops are very infrequent, and such a service can be operated at a less cost and will attract more traffic than the competing steam line with its antiquated method of operating with steam locomotives.

Suburban roads, however, that pick up their load at frequent intervals along the route and still have to compete with parallel steam lines, present problems much more difficult to solve from an economic standpoint. It is the custom of such roads to establish stopping points, say one mile or less apart, and stop at these points only on signal. During certain portions of the day, however, cars will be obliged to stop at nearly all these stations, and will either fall behind their schedule at such times or will have too much leeway during the remainder of the day when stops are much less frequent. Moreover, owing to the considerable city running at necessarily slow speeds, these suburban roads must make as good time as possible on the suburban route in order to bring the passengers from the more distant points within a reasonable time, including city running. In fact, such roads when paralleling steam lines operating on private right of way through the city, and moreover giving excellent service morning and night to commuters, are compelled to face very

serious engineering and economic problems due to the tremendous amount of generating apparatus, line copper and motive power required to give equally good service.

A suburban road will develop a considerable amount of traffic, due to its frequent service, but there comes a time when such roads will extend beyond the zone of half hour runs into the city and try to reach the outlying districts hitherto belonging exclusively to the steam lines. The frequent service will always be a valuable asset and one that cannot be duplicated with the steam locomotive, except at higher cost of operation, but if it takes considerably longer to reach the city by means of the electric line than by the steam road with its better facilities for high speed, the electric line will fail to obtain the proportion of suburban business to which it has been accustomed in its more limited scope. In other words, it fails in its purpose, due to the frequent stops to which its previous popularity was due.

In considering the proper speed at which to operate a new electric line, it is necessary therefore to go very carefully into local details and especially canvass the competition with existing steam lines not only when operated in their present form, but also consider the possibility of their adopting electricity as a motive power.

In considering the possible speeds of a car or train of cars, the investigator is met with the necessity of obtaining some accurate data on the question of car and train friction. The greater part of the data now existing on this subject has been obtained with trains hauled by steam locomotives. Many of these results were obtained by draw-bar pull and hence neglected the wind-friction of the locomotive, and those taken by indicator diagrams are open to the objection that the steam locomotive is not square ended like a car and wind-friction results so obtained are not applicable to the operation of the train electrically without locomotive. Moreover, all these results were obtained with more than a single car in the train and do not apply to suburban electrical operation which almost universally uses single car trains. Tests are being made from time to time with electrically operated trains, and due to the refinement of the carefully calibrated voltmeter and ammeter it is possible to obtain wind-friction values at various speeds and with different number of cars in a train with greater accuracy than in the previous steam tests. These results are not at all complete and the only attempt known to the writer to obtain friction values with different number of cars was made

by W. J. Davis, Jr., through the courtesy of the International Railway Company on its Buffalo & Lockport line in March, 1900. Using these tests as a basis, the writer has drawn up three friction curves in Fig. 1, designating them A, B and C.

The C curve will hold approximately for single car operation where the car weighs in the vicinity of 40 tons. The B curve

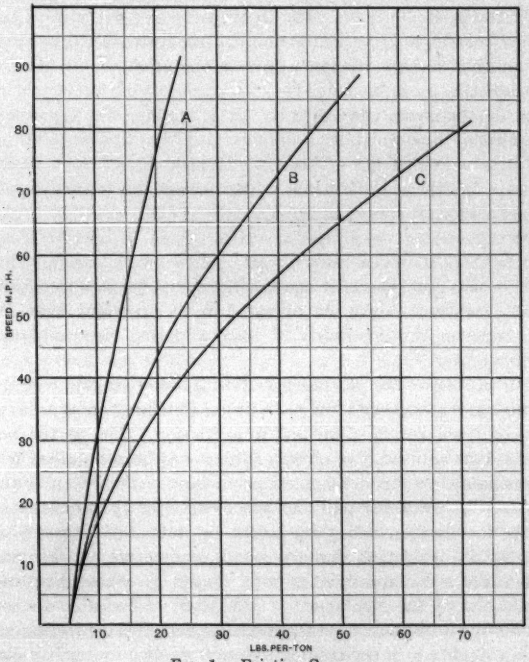

FIG. 1.—Friction Curves.

applies to the operation of two such cars in a train and the A curve to a train of such cars, say eight or more in a train. These curves are not published with the idea that they are correct, in fact the speeds at which they were obtained do not exceed 60 m.p.h., and hence extension beyond this speed is based upon a formula which will follow curve shape up to 60 m.p.h. As the results obtained by using them are not dependent upon their

numerical values, intermediate points being easily interpolated, it is not of prime importance that the three friction-curves given represent accurately the conditions as set forth. In fact, with the different shaped cars now in use and the different cross-section of cars having the same weight, etc., it is hardly possible to make one friction-curve which would apply accurately to all cases. It is probable, however, that the curves given have the general shape and the numerical values applying to average conditions. The friction curves have been extended to maximum speeds approaching 90 m.p.h. in order that questions of motor capacity, train energy, possible schedule speeds, etc., can be followed up to maximum speeds equal to or better than those in vogue on the present steam roads. As will be pointed out later in this paper, the consideration of the proper method of operating a railway service at these high maximum speeds leads to very interesting results as determining the size of trains and frequency of service to be adopted.

With the friction curves in Fig. 1 as a basis, the curves in Figs. 2, 3 and 4 have been calculated, showing the possible schedule speeds and energy consumption required for these speeds up to and including 75 m.p.h. maximum. The method used in making up these curves is similar to that pointed out in a paper entitled A STUDY OF THE HEATING OF RAILWAY MOTORS presented by the writer at the annual meeting of the INSTITUTE in 1902. As indicated in that paper, the rate of acceleration and rate of braking do not have a marked effect on the energy consumption or possible schedule speeds for these comparatively high-speed roads. The shape of the motor characteristic also is not a determining feature and can be neglected without introducing a possible error of more than a few per cent. The controlling factor in all of these curves is the friction-curve, which includes track, rolling, journal and wind-friction.

The constants assumed in calculating the above curves are those pertaining to average high-speed suburban work as follows:

Gross accelerating rate ..... 120 lbs. per ton
Braking effort (average) ..... 120 " " "
Duration of stop..... 15 seconds each.
Track assumed to be perfectly straight and level.

In the above curves, due consideration is given to all the losses occurring during acceleration with the standard series-parallel controller and direct current motors. If the curves are to be used

for alternating current motors, allowance must be made for the difference in accelerating efficiency of the two types of motors and their methods of control. The inertia of the rotating parts of the equipment generally amounts to 5 per cent. and this value is taken throughout, being perhaps a little high for the higher speeds and low for the lower speeds. The speed-curve of a standard 125 h.p. motor is used throughout. The energy curves

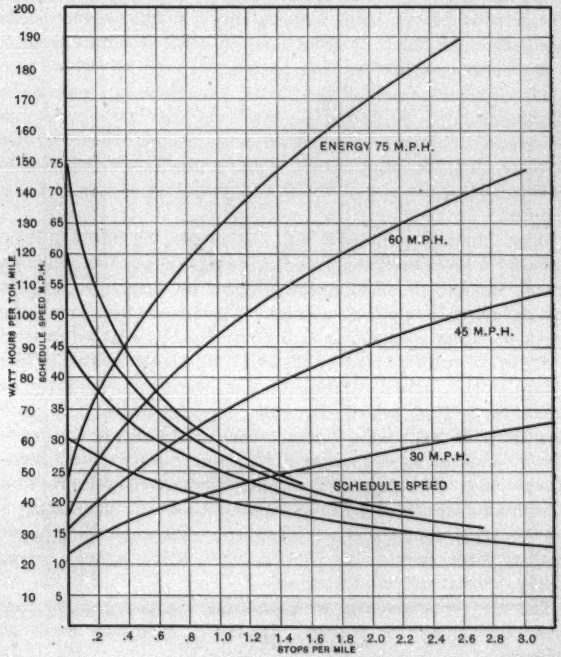

FIG. 2.—Speed and Energy Curves. A. Friction Curve.

given are somewhat affected by the amount of coasting done, although this is not so determining a factor in this high speed work as it is in slow speed rapid transit accelerating problems. In order that the energy curves should be conservative, they are plotted with only 10 seconds of coasting permitted and therefore the schedule speeds given are nearly the maximum possible, and

the energy curves given are also practically the maximum possible with the maximum speeds assumed. Should power be shut off earlier and more coasting permitted, the energy consumption would have been decreased and the schedule speeds decreased somewhat also, especially with the more frequent stops per mile.

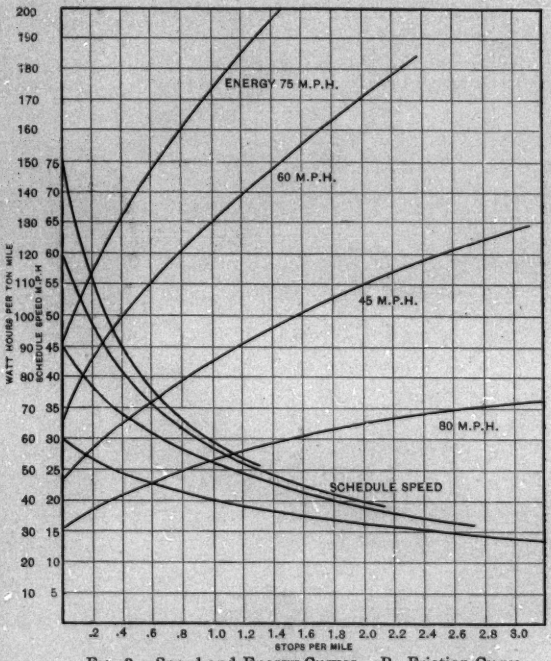

FIG. 3.—Speed and Energy Curves. B. Friction Curve.

An inspection of these three sets of curves will bring out the very great effect of the wind-friction when using trains of one or two cars at very high speeds, in fact at 75 m.p.h. maximum speed the operation of single car trains becomes impracticable with light 40 ton cars of standard construction, and even at 60 m.p.h. is questionable. To quote from the curves, it requires an energy

consumption of 47 watt-hours per ton-mile for a train of several cars, as against 137 watt-hours per ton-mile for a single car operating at 75 m.p.h. without stops; that is, a single car operation would demand 3.7 times the energy per ton that would be required for the operation of a train of many similar cars. Even a two-car train will require but 92 watt-hours per ton-mile, or

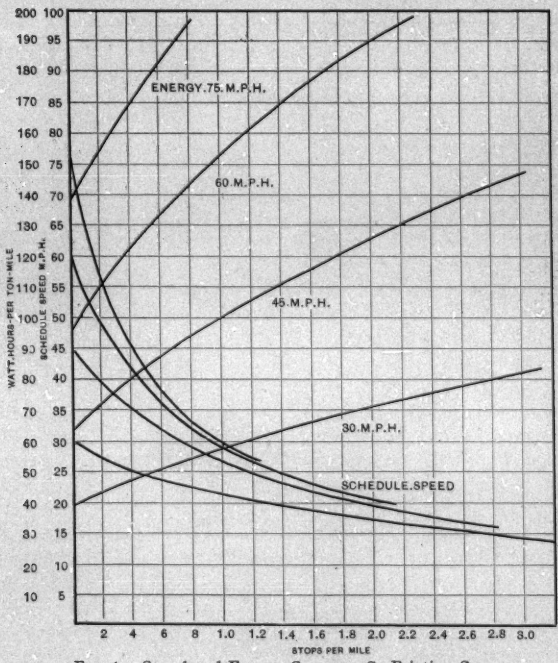

FIG. 4.—Speed and Energy Curves. C. Friction Curve.

only 67 per cent. of the energy required per ton for single car operation. As these values are for constant-speed running, while more or less frequent stops would obtain, a comparison at say one stop in 4 miles would be nearer the actual results in practice. Here a single car requires 157 watt-hours per ton-mile, a two-car train requires 120 and a train of several cars 79 watt-hours per ton-mile. The results would indicate that in a

class of service calling for very high maximum speeds, the tendency of electric roads will be to follow steam railroad practice and operate trains of several cars at more infrequent intervals rather than follow present practice of suburban electric roads and run single cars at frequent intervals. It will be a question for local consideration whether sufficient additional traffic would be gained by the operation of single cars, say on half hour headway, or trains of two or three cars on one hour headway or more, the latter requiring but 60 or 70 per cent. of the power per ton moved, and also effect a considerable saving in train crew expenses. As the maximum speed of the service is reduced the difference in energy consumption between single cars and trains of cars is also reduced and at 30 m.p.h. a single car will require but slightly more energy per ton than a train when operated at the frequent stops characteristic of low speed service.

Another very interesting feature which is well known but perhaps not fully appreciated is brought out by the curves of schedule speeds possible for different maximum speeds. Thus, with one stop in 8 miles it is possible to make a schedule of 61 m.p.h. with maximum speed of 75 m.p.h., and a schedule of 28 m.p.h. with maximum speed of 30 m.p.h. If stops be increased so that they average one per mile, however, the schedule speed possible with a maximum speed of 75 m.p.h. is dropped to 29 m.p.h., while the 30 m.p.h. maximum speed permits of a schedule speed of 22 m.p.h. Thus while 30 miles is but 40 per cent. of the higher maximum speed it permits a schedule at one stop per mile of 76 per cent. of that possible with 75 m.p.h. maximum speed. The fallacy of using high-speed equipments for frequent stops is forcibly brought out by referring to the energy curves in Figs. 2, 3 and 4. With one stop per mile it requires 200 watt-hours per ton mile with 75 mile maximum speed equipment, and the 30 miles maximum speed equipment can obtain 76 per cent. of the same schedule with an expenditure of only 28.5 per cent. of the energy. The two values taken for the maximum speed are the extreme, but serve the purpose of bringing out the tremendous price paid for high schedule speeds at frequent stops. The conditions of acceleration and braking are the same in both these equipments, while if higher schedule speeds were required with, say, one stop per mile, a higher rate of acceleration and, if practical, a higher rate of braking would be adopted. The difference in energy values would be considerably

reduced thereby, but neither the average rate of acceleration nor the braking could be very largely increased without incurring the possibility of discomfort to passengers.

Before considering the application of the previous curves to a concrete case, it is necessary to include the effect of the different friction curves at high speeds upon the capacity of the motor equipment. In the paper by the writer at the last annual meeting of the INSTITUTE, the manner of fully determining the capacity of a motor for any service was indicated. The details of this method will not be gone into in the present paper, but for convenience a sample motor capacity-curve of a 125 h.p. equip-

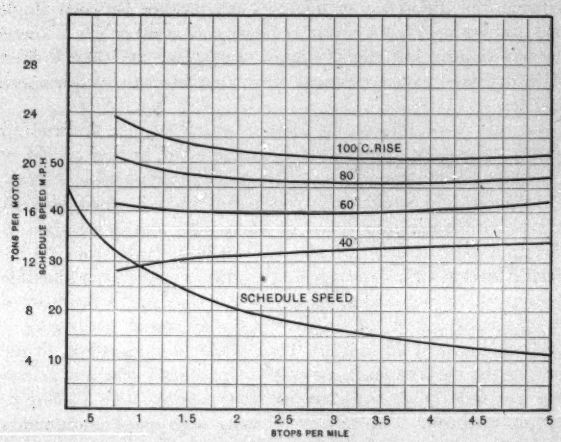

FIG. 5.—Motor Capacity Curves 125 H. P. Motor. B. Friction Curve.

ment operating at a maximum speed of 45 m.p.h. is shown in Fig. 5.

The means taken to determine the capacity of this motor is to obtain from a series of temperature runs made upon an experimental track the degrees rise per watt loss in different parts of the motor for different ratio of losses for armature and field. It is obvious that so long as the motor losses and their distribution are the same, the temperature rise of the different parts of the motor will also be practically the same. This assumes that the car will travel at the same average speed, which is not necessarily the case owing to the fact that the same motor cycle could be

obtained with a considerably different train cycle. A service capacity-curve similar to Fig. 5 on the 125 h.p. motor is therefore not absolutely correct unless the thermal capacity curves be obtained from actual tests giving the same train-cycle as that indicated. It is not necessary to conduct so elaborate a series of tests, as a sufficiently close result can be obtained for practical purposes by obtaining the experimental thermal capacity curves at moderate average speeds upon an experimental track, and assuming that the conditions of ventilation so obtained will hold true for all the schedule speeds. It is admitted that a source of error is thus introduced and that motor service capacity curves will read too conservative at the very high speeds and will

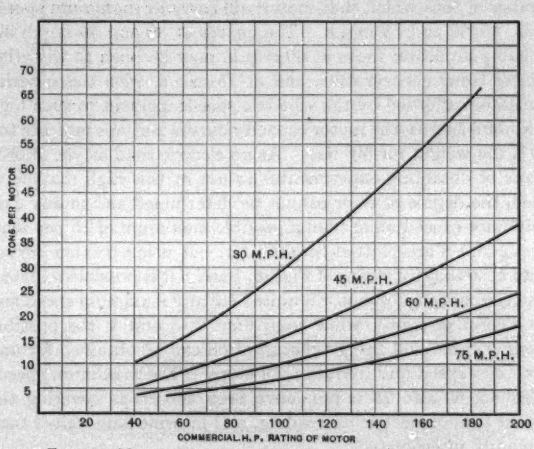

FIG. 6.—Motor Capacity 60° C. Rise. A. Friction Curve.

possibly be too liberal at the lower speeds; but conservatism at speeds approaching 75 m.p.h. could not be criticised as poor engineering, and the results given in following curves are therefore presented with full confidence that they will meet a long felt want and will moreover be approximately correct for types of motors similar to those serving as basis of calculation and experiments.

An inspection of the curves given in Fig. 5 discloses the fact that for a given temperature-rise the capacity in tons per motor is practically a fixed amount. For example, a temperature rise

of 60° C. will be obtained with approximately 16.2 tons per motor over a range extending from one stop in four miles to five stops per mile. It is thus sufficient to associate a given motor and gear ratio with a definite car weight which it can operate with a given temperature-rise, and with any schedule speed which the number of stops per mile will permit. This at once affords a means of comparing motors of different capacity by means of the "tons per motor" which is permitted for say 60° rise and a given maximum speed equipment. In presenting the curves in Fig. 6, the results of a large number of experiments and calculations are incorporated on motors of similar design giving the relation between the commercial one hour rating of the motor and the number of tons which that motor will carry at maximum speeds of 30, 45, 60 and 75 m.p.h. The curves of 30 and 45 m.p.h are probably accurate, those at 60 m.p.h. may be open to the criticism of being conservative, and at 75 m.p.h. with the superior ventilation afforded by the schedule speeds incident to such high maximum speeds, the motor capacity curves perhaps indicate too low a ton weight for 60° rise. As no electric road as yet affords means of obtaining experimental values at this high maximum speed, the degree of error cannot be determined and in any case should not exceed more than a possible maximum of 15 per cent. Figs. 7 and 8 are plotted for 60° also, but using friction curves B and C, so that by means of Figs. 6, 7 and 8 it is possible to determine the capacity of motor required for any maximum speed and any weight of train; while from Figs. 2, 3 and 4, the possible schedule speed and energy consumption can be obtained for any maximum speed and frequency of stops. The maximum speeds of 30, 45, 60 and 75 m.p.h. have been chosen as covering the present field of electric railroading, and intermediate values may be readily interpolated.

The relation between the commercial one-hour rating of a railway motor and its service capacity-performance is very difficult to express. In fact, it is almost impossible to compare two motors differing essentially in their mechanical design, as the stand-test of a motor has no direct bearing on its service performance with its different distribution of losses and better facilities for ventilation. It is necessary therefore to obtain by experiment the performance of each individual motor under conditions approximating service operation, and determine the relation of stand-test to service operation for the particular motor in question. By carrying on a series of exhaustive tests on each

individual motor it becomes possible to plot the results of such tests in curve form and show the relation between stand tests and service capacity, provided motors are of the same general design. Having obtained the capacity in tons per motor for different maximum speed equipments, the results were all found to follow the general law noted in Fig. 5; that is, the temperature-rise was found to be practically constant over a wide range in stops per mile and schedule speed. With this simplification it becomes possible to compile curves 6, 7 and 8, giving the capacity motor required for any train weight, schedule and frequency of stops, the motors all being of similar design. These curves are all

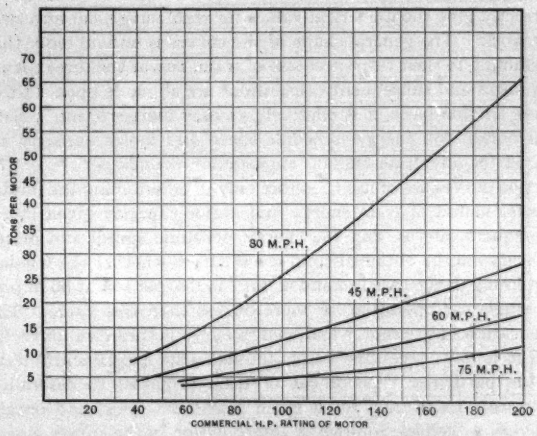

FIG. 7.—Motor Capacity 60° C. Rise. B. Friction Curve.

plotted with motors of the closed type, it being assumed that in miscellaneous operation advantage cannot be taken of opening ventilators. Where motors can be operated partially or fully open, the capacity, especially at high speeds, will be considerably increased. It is probable, however, that motors operating at speeds approaching 60 to 70 m.p.h. will be upon a surface track where it would be advisable to protect the motor from dust and moisture, and thus operate closed.

The results brought out by curves, 6, 7 and 8 are very instructive as determining the probable trend of very high speed electric railroading where trains of one or more cars are used. For

example, a 40 ton car equipped with four motors, thus giving 10 tons per motor, will require a 133 h.p. motor for 60° rise when operating a train of several cars at 75 m.p.h. maximum speed, while the same weight of car would require a motor of at least 230 h.p. if operated as a single car with the same temperature rise and similar design of motor. That is, the motive power is doubled in going from train to single car service. Thus not only is train friction the determining feature of energy values, but it is the controlling feature as well of the motor capacity required to perform a given high speed service.

As pointed out in the earlier part of this paper it is not necessary that the friction curves A, B and C shall in themselves correctly give the numerical values for train, single-car and two-car work. The general shape of the curves is undoubtedly that pertaining to their respective size of train, and as the three curves are taken and subsequent calculations are all made upon a three curve friction basis, it is relatively an easy matter to interpolate and obtain the energy, schedule speed and motor capacity required for any train-friction expressed in pounds per ton. The friction curves are of use therefore only in determining the fundamental values of train energy and motor capacity given in the subsequent curves, and the energy, schedule speed, and motor capacity can be obtained from these curves whether the friction pertaining to the case in hand is, say, 33 lbs. per ton at 50 m.p.h. for single car operation, or more or less than this value. The application of the motor and energy curve is therefore universal and it is only necessary to obtain sufficient experimental data of the particular type of car or train proposed to determine accurately its friction for a given maximum speed and obtain the various values required by interpolation in the curves given.

Having obtained the data upon which to base calculations for the proposed electric road, perhaps the best method of showing its application would be to take a concrete case. Let the distance from A to B be, say, 100 miles, or great enough to get over the consideration of location of substations in relation to the length of the line. Assume also that the proposed road will parallel a steam line, or that there are other reasons necessitating a high schedule speed, and that stops will occur every four miles and will be of 15 seconds duration, and that the motors will be direct current supplied from substations fed from a single central generating station. It is desired to know the effect that single car or train operation will have upon first cost and cost of operation.

It is assumed that the competing steam road will have a schedule speed in the vicinity of 40 m.p.h. Such express trains as exceed this schedule will offer such very infrequent service, and will furthermore be so restricted to their through travel that they will not enter as a factor for consideration. By referring to Fig. 4 we find that a schedule speed of 40 m.p.h. can be obtained with a maximum speed of approximately 48 m.p.h. with one stop in four miles. The energy consumption will be 82-watt hours per ton-mile and the motor capacity will consist of four 110 h.p. motors operating a single 40 ton car with a temperature rise of 60° (Fig. 8). The energy consumed at the car will therefore be

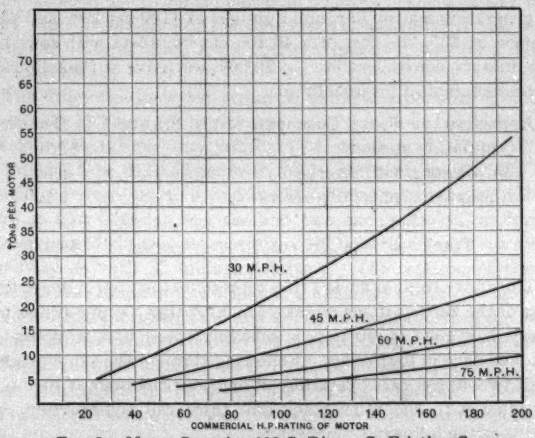

FIG. 8.—Motor Capacity 60° C. Rise. C. Friction Curve.

131 k.w. or 144 k.w. at the substation busbar, allowing an average drop of 10 per cent. in the third rail. With a substation busbar potential at 600 volts, each car will average 240 amperes.

Assuming that the road will be double track with 80 lb. track rails and 100 lb. third rail, the distance apart of the substations will be approximately 13 miles with a maximum drop of 170 volts when two cars are passing midway between substations, one of which is accelerating. This drop is permissible as it is momentary only. Each substation must be able to accelerate one car and supply another at full speed, or must give 850 amperes momentary output and a sustained output of 500 amperes. The

substation will therefore be called upon to deliver momentarily 510 k.w. and should contain not less than one 300 k.w. rotary converter and preferably two, one being a reserve. This size of converter is based upon the assumption that cars run always as single units and not in trains, and that converters can stand a momentary over-load of 100 per cent. With half-hour service cars will be spaced 20 miles apart, so that there will be required a generator capacity of two cars every 20 miles (double track) or 340 k.w. assuming 15 per cent. loss in rotary converter substations and transmission line. The generating station capacity per mile of track will therefore be 17 k.w., and the substation 46 k.w. with reserve, and 23 k.w. with no reserve. Taking the cost of generating station in round numbers at $100 per k.w. and substation at $35, the cost of a 40 ton car complete with four 110 h.p. motors, controllers, etc., at $9,000, we arrive at the following approximate cost for installing:

Approximate First Cost per Mile, Single Car Train.	
Generating station	$1,700
Substations with reserve	1,610
Equipment (plus 20% reserve)	1,120
Total	$4,430

The above total of $4,430 thus represents the approximate first cost of the various items noted when operating a single 40-ton car every half-hour at 40 m.p.h. schedule speed and stopping 15 seconds once in four miles. Following through the same process with two 40 ton cars operating on one hour headway at 40 m.p.h. schedule with the same track and third rail construction, we arrive at the following conclusions:

Watt hours per ton mile	63
Train energy at train (80 tons)	202 k.w.
Distance apart substations	9.1 miles.
Size of substation	two 400 k.w. units.

Each train consisting of two 40-ton cars will consume 224 k.w. at the substation, or 264 at the generating station, allowing the same percentage of loss as above. These trains making the same schedule speed at double the headway will be spaced 40 miles apart and the generating capacity will therefore be 528 k.w. every 40 miles, or 13.2 k.w. per mile. The substations consisting of two 400 k.w. units (with reserve) every 9.1 miles will have capacity per mile of 88.0 k.w. Expense for cars will be the same as before and the following approximate costs obtain:

Approximate First Cost per Mile. Two Car Train	
Generating station	$1320
Substations	3080
Equipments	1120
Total	$5520

The first cost of the two-car train system will be $5.520 as against $4,430 with single-car train. The energy consumed for the two methods of operation is 17 k.w. per mile of track with single car as against 13.2 k.w. per mile with two-car train. Thus, while the two-car train at one hour headway will cost 24½ per cent. more to install (for the items mentioned only) it will consume but 77.6 per cent. of the energy required to operate a single car individually.

The difference in power required, is 3.8 k.w. per mile of track. Assuming 12 hours per day operation at the above headway, the total k.w. hours per day will be 45.5, which at $.007 per k.w. hour would be $116.50 per year, or 10 per cent. on $1,165. It would therefore pay to invest the $1,090 per mile of track difference in cost between one car and two car operation, as found above, provided the same receipts could be secured with one hour headway as with 30 minute headway. The relation of traffic receipts and frequency of travel is a question which can only be determined experimentally, and while the desirability of the two-car service seems evident from the data at hand in the above case, it might result in a falling off of receipts, to such an extent as to more than make up the saving in operating expenses. There is an additional saving in train crew expenses which was not entered into above, and which would amount to something more than half as much as the cost of power. With two-car operation, it is possible to reduce the motor capacity per car from four 110 h.p. motors to four motors of approximately 95 h.p., thus reducing the cost of the equipment item. Owing to the fact, however, that it might be desired to operate a single car during certain parts of the day, which would result in overheating the smaller motor equipment, it would be more conservative to consider the same size of equipment whether one-car or two-car train were operated. With more than two cars in a train, advantage could be taken of the smaller equipment required, but it is probable that in two-car work this advantage of the smaller motor possible for two cars would only result in the cooler operation of these motors

when operated in two-car trains and would show up therefore in the repair account rather than as a first cost. The substations with two-car trains being placed somewhat closer together would have a labor account per mile of track in excess of that for single car operation. This may be balanced against the saving which would result from smaller crew expenses of the two-car train.

These examples serve to illustrate the very broad application of the foregoing curves. Although it has been necessary to assume a number of constants, acceleration, braking, coasting, etc., these constants are those pertaining to average operation and can vary considerably without making a serious difference in the results. The curves given are not therefore absolutely correct, but are sufficiently so for approximation purposes. For the slower speed work where stops are more frequent and where acceleration is a more important factor, it will be necessary to have more complete curves to determine the proper rate of acceleration to use, especially if the problem is one calling for very high schedule speeds in relation to the number of stops.

As previously stated, it is not necessary that friction curves A, B and C should represent the actual friction in pounds per ton of train two-car and single-car work. Having the motor capacity and energy values for three different friction rates at a given maximum speed, it is possible to interpolate and secure the proper motor capacity and energy value for the friction value corresponding to the case in hand. The importance of the wind-friction as affecting electrical operation at a very high speed in service which has followed along the lines of very small light trains of one or more cars, will probably lead to the construction of special cars reducing wind-friction to a minimum when the higher maximum speeds are put into commercial operation. No conclusive data is at hand upon the effect of different shaped car ends on single or two-car operation. When such data becomes available and special cars are constructed, their operation can be predicted from the foregoing curves by interpolation for the new friction values thus obtained.

The compilation of the above curves entailed a large amount of careful work, and the writer is very much indebted to E. F. Gould for his very valuable assistance.

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STORAGE BATTERY INDUSTRIAL LOCOMOTIVES.

BY F. L. SESSIONS.

General treatment of subject of equipment of industrial locomotives with storage batteries. Batteries employed as (1) the only source of energy supply; (2) as the main source of energy supply; (3) as an auxiliary source of energy supply. Arrangements for charging. Relation of energy storage and discharge capacities to locomotive duty. Data, tables and examples of their use.

Among the various agents employed in handling material about industrial plants, the electric storage battery is taking a position of prominence. The limits of its field of usefulness for street and interurban railway service have been pretty thoroughly determined by costly experiment and the calculations of competent engineers. It is probable that conclusions which have been reached in such service have until recently been considered applicable to other services in which the storage battery might be used. The demands of recent industrial activity have, however, caused engineers to give much attention to the handling of material, and carefully to determine the energy and power requirements of the problems involved. This has led to the development of a great many devices and machines for reducing the time and expense of handling material. The study of such problems of different magnitudes has led the writer to the conclusion that the energy and power demands of many of them are well within the range of electric storage battery service, and the results already achieved with storage battery industrial locomotives have fully proved the conclusions reached.

Among the prominent advantages of these locomotives are convenience, safety and economy. No other form of industrial locomotive can compete with the storage battery in the matter of convenience. It can be operated at night when other sources of power are cut off; it can be operated by an inexperienced person; it is ready for operation the instant it is required; it can be used as an energy supply for running motors or furnishing light when-

ever the usual power supply is cut off; it can be run over temporary tracks on wooden rails in special or emergency cases.

The storage battery locomotive also excels in safety. Very few establishments are so arranged that either the overhead trolley or third rail conductor would not be a source of inconvenience or danger at some if not all parts of the system of tracks necessary for the most convenient handling of material. Frequently where it is permissible to employ either a trolley or third rail conductor over parts of the system, it is found prohibitive in other parts where a locomotive would be of most value. This is particularly the case in shops where overhead cranes and

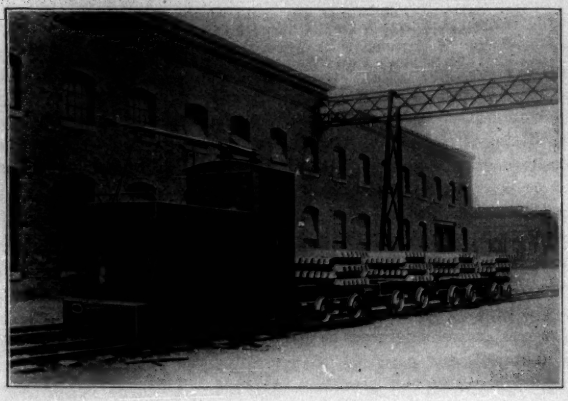


FIG. 1.

belting are used, and in buildings wherein inflammable materials are handled or stored.

In the matter of economy it is probable that the storage battery locomotive equals any other. Its average efficiency is as high as that of any other, and although on high discharge rates the battery efficiency may be low, the fact that when the locomotive is idle no energy is being used compensates for the low efficiency during high discharge periods.

While the storage battery requires care and attention and may be rendered unfit for service through improper treatment or neglect, it is nevertheless true that any person of ordinary intelligence can readily learn to care for and operate it successfully and to cure its ordinary ills. Reduced to simple terms the require-

ments for the successful maintenance of an electric storage battery are that the attendant perform a number of mechanical operations each day or at stated times, and take readings from certain instruments which are easier to learn to read than it is to learn to tell time by the ordinary clock. If these readings differ from prescribed figures, the attendant must perform other simple mechanical operations which produce results in the battery about which the attendant need have no knowledge, but which restore the cells to their normal condition.

In this paper all statements and data which may depend upon the type of storage battery, refer only to the usual lead-lead type, as that to date is the only successful electric storage battery available for use upon industrial locomotives.

In considering the equipment of a storage battery locomotive, the subject will be divided under the following heads: batteries, motors, control and protection.

BATTERIES.

In the equipment of a locomotive with a storage battery, the conditions of service and work to be performed determine the capacity of the battery to be used. In some instances a heavy locomotive may best be provided with a small storage battery, while in others it may be best to equip a light locomotive with the largest storage battery possible. In general, a storage battery upon a locomotive is employed to fill one of the three following offices:

1. It may be employed as the only source of energy supply.
2. It may be employed as the main source of energy supply.
3. It may be employed as the auxiliary source of energy supply.

Batteries used for any one of these three purposes may be arranged to be charged.

(*a*) While on the locomotive at a charging station.

(*b*) While on the locomotive operating on trolley or third rail.

(*c*) While removed from the locomotive.

A locomotive may be equipped with a storage battery as its only source of energy supply, when the duty is such that it can be performed on a single charge, or when there are times in which the battery may be charged on the locomotive at a charging station, or when two or more sets of batteries are provided and a fully charged battery is placed on the locomotive whenever the one in use becomes discharged.

A storage battery may be employed as the main source of energy supply, and a trolley or third rail conductor used on por-

tions of the track where excessive grades, sharp curves, heavy loads or other conditions render the storage battery inadequate.

As an auxiliary source of energy supply, a storage battery may be used on locomotives running partly within buildings or portions of yards where safety, convenience or other reasons make a trolley or third rail conductor undesirable, but where on other parts of the track the trolley or third rail conductors are permissible and desirable.

It will readily be seen that an accurate knowledge of the conditions of service and of the work to be performed is necessary before determining what battery equipment to provide. In determining the capacity of a storage battery for any installation, the principal requirements are to provide a sufficient energy storage capacity, and one which can develop sufficient power for

FIG. 2.

the maximum demands. To move a given load a given distance will require the expenditure of the same amount of energy whether the work is done in one minute or ten minutes; but to move the load over the distance in one minute will require ten times the power that is required to do the work in ten minutes. For either case a storage battery could have the same energy storage capacity, but in one case the battery should be capable of delivering its energy ten times as fast as is necessary in the other case. The amount of energy which a fully charged storage battery can deliver depends upon the rate at which the battery is discharged. If discharged at a low rate its storage capacity is less than when discharged at a high rate. If the rate of discharge is too high, the battery deteriorates rapidly. In general, the one hour rate is the highest at which a battery should be regularly discharged.

although for short periods a higher rate may occasionally be used. In selecting a storage battery for a locomotive, it is therefore important that the maximum power required does not exceed the one hour discharge rate, except momentarily as in starting loads; and that the energy storage capacity is great enough to enable the locomotive to perform the duty required of it.

To facilitate calculations in the choice of a battery, a number of tables have been prepared, based upon units which make their use available for a wide range of problems and battery capacities.

Table I. gives the kilowatt hours and draw-bar pull required to move one ton one hundred feet under different friction loads and on various grades at any speed. By multiplying the kilowatt hours of this table by sixty, we obtain the actual power in kilowatts required to move one ton one hundred feet per minute.

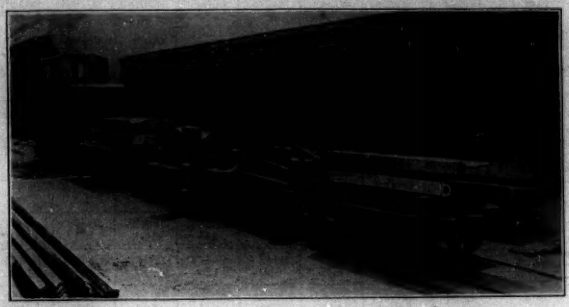


FIG. 3.

With this table, we are, therefore, able to determine both the energy storage capacity and the kilowatts discharge rate necessary for any given duty.

The solution of the following problem will illustrate some of the uses of this table. A locomotive is required to haul 50 tons, including its own weight, up a 2 per cent. grade against a frictional resistance of 30 lbs. per ton a distance of 2,000 feet at a speed of 400 feet per minute. It is required to know: (1) The energy and (2) the power necessary.

The table gives .00264 k.w. hours to haul one ton up a 2 per cent. grade when the frictional resistance is 30 lbs. per ton; to haul 50 tons 2,000 feet will, therefore, require $.00264 \times 50 \times 20$ which equals 2.64 k.w. hours of energy.

To obtain the power in kilowatts necessary to move one ton

TABLE I.

HAULAGE DATA.

Kilowatt hours and drawbar pull required to move one ton 100 feet under different friction loads and on various grades at any speed.

Grade.	Frictional resistance in pounds per ton on level track.							
	50	40	35	30	25	20	15	10
Level.	.001885 50	.001515 40	.001323 35	.001135 30	.000943 25	.000758 20	.000568 15	.000379 10
½%	.00226 60	.001885 50	.001696 45	.001515 40	.001323 35	.001135 30	.000943 25	.00758 20
1%	.00264 70	.00226 60	.00207 55	.001885 50	.001696 45	.001515 40	.001323 35	.001135 30
1½%	.00302 80	.00264 70	.00245 65	.00226 60	.00207 55	.001885 50	.001696 45	.001515 40
2%	.0034 90	.00302 80	.00282 75	.00264 70	.00245 65	.00226 60	.00207 55	.001885 50
2½%	.00377 100	.0034 90	.00323 85	.00302 80	.00282 75	.00264 70	.00245 65	.00226 60
3%	.00415 110	.00377 100	.00358 95	.0034 90	.00323 85	.00302 80	.00282 75	.00264 70
3½%	.00452 120	.00415 110	.00396 105	.00377 100	.00358 95	.0034 90	.00323 85	.00302 80
4%	.0049 130	.00452 120	.00434 115	.00415 110	.00396 105	.00377 100	.00358 95	.0034 90
4½%	.00528 140	.0049 130	.00472 125	.00452 120	.00434 115	.00415 110	.00396 105	.00377 100
5%	.00566 150	.00528 140	.00509 135	.0049 130	.00472 125	.00452 120	.00434 115	.00415 110
5½%	.00604 160	.00566 150	.00547 145	.00528 140	.00509 135	.0049 130	.00472 125	.00452 120
6%	.0064 170	.00604 160	.00585 155	.00566 150	.00547 145	.00528 140	.00509 135	.0049 130

Multiply the constant by 60 to obtain kilowatts for one ton 100 feet per minute.

$$\text{k.w. Hrs.} = \frac{\text{Constant} \times \text{Tons} \times \text{Hundreds of feet}}{\text{Locomotive Efficiency.}}$$

$$\text{k.w.} = \frac{\text{Constant} \times 60 \times \text{Tons} \times \text{Hundreds of feet per minute}}{\text{Locomotive Efficiency}}$$

one hundred feet a minute up a 2 per cent. grade with a frictional resistance of 30 lbs. per ton, the constant .00264 must be multiplied by 60 which gives .1584 k.w., and to haul 50 tons 400 feet per minute against the same resisting forces will require .1584 $\times 50 \times 4 = 31.68$ k.w.

The above calculations assume a locomotive efficiency of 100 per cent., which is impossible. If this efficiency is 70 per cent. then the energy required is $2.64/.7 = 3.78$ k.w. hours, and the power is $31.68/.7 = 45.25$ k.w.

TABLE II.

STORAGE BATTERIES.

Total Kilowatt Hours available and Kilowatts discharge rates for batteries of different 8-Hour ratings.

Nominal or 8 Hr. Rating.	Kilowatt Hours.								
	5	10	15	20	30	40	60	80	100
5 Hrs.	4.38	8.75	13.12	17.5	26.25	35.	52.5	70	87.5
4 "	4.05	8.1	12.15	16.2	24.3	32.4	48.6	64.8	81
3 "	3.75	7.5	11.25	15	22.5	30	45	60	75
2 "	3.25	6.5	9.75	13	19.5	26	39	52	65
1 "	2.75	5.5	8.25	11	16.5	22	33	44	55
Nominal or 8 Hr. Rate.	**Kilowatts.**								
	.63	1.25	1.88	2.5	3.76	5	7.5	10	12.5
5 Hrs.	.88	1.75	2.63	3.82	5.25	7	10.5	14	17.5
4 "	1.01	2.03	3.04	4.05	6.08	8.1	12.15	16.2	20.3
3 "	1.25	2.5	3.75	5	7.5	10	15	20	25
2 "	1.63	3.25	4.88	6.5	9.75	13	18.5	26	32.5
1 "	2.75	5.5	8.25	11	16.5	22	33	44	55

A battery capable of discharging 45.25 k.w. on a one hour discharge rate has a storage capacity of 82.3 k.w. hours on an 8-hour discharge rate, as determined from the data given in Table II. Such a battery would be capable of operating under such a load continuously for one hour on one charge, as its storage capacity on a one hour discharge rate is 45.25 k.w. hours.

Table II. gives the total kilowatt hours available and the kilowatts discharge rates of batteries of different nominal, 8 hour ratings. The corresponding quantities for a battery of any

other capacity may be obtained by multiplying those for a 100 k.w. hour battery by the relative capacity of the battery desired.

Table III. gives the total tons load that can be hauled by a 100 k.w. hour storage battery on various grades and with different frictional resistances at 100 feet per minute when the locomotive efficiency is 100 per cent. From this table may be computed the total ton loads that anybattery can haul at any speed. For example, let it be required to determine what load a 40 k.w. hour battery can haul on a 2½ per cent. grade at a speed of 150 feet per minute when the frictional resistance is 30 lbs. per ton. In Table III. under 30 lbs. frictional resistance and 2½ per cent. grade is given 304 tons as the total load that can be hauled by a 100 k.w. hour battery at 100 feet per minute. A 40 k.w. battery can, therefore, haul $304 \times 40/100 \times 100/150 = 81.2$ tons, under the conditions assumed in the problem. If the locomotive efficiency is 70 per cent., it will be able to haul $81.2 \times .70 = 56.84$ tons, including its own weight and that of the battery.

Table IV. gives the kilowatts for hauling 100 tons 100 feet per minute on various grades and with different frictional resistances. From this table may be computed the kilowatts for hauling any load at any speed. For example, let it be required to determine the capacity of a battery for hauling a total of 50 tons at 250 feet per minute on a 1 per cent. grade when the frictional resistance is 25 lbs. per ton. In Table IV. under 25 lbs. frictional resistance and 1 per cent. grade is given 10.2 k.w. for hauling 100 tons 100 feet per minute. To haul 50 tons at 200 feet per minute will, therefore, require $10.2 \times 50/100 \times 250/100 = 12.75$ k.w. If the locomotive efficiency is 70 per cent., a storage battery for such a duty should have a discharge capacity of $12.75/.7 = 18.21$ k.w.

Table II. may be used to determine the nominal k.w. hour rating of a battery having a discharge capacity of 18.21 k.w. In this table a 100 k.w. hour battery is seen to be capable of discharging 55 k.w. for one hour. The k.w. hour rating of a battery capable of discharging 18.21 k.w. for one hour will be proportional to that of the 100 k.w. hour battery, or the battery required will have a nominal storage capacity of $18.21/55 \times 100 = 33.1$ k.w. hours.

The foregoing problems are given as illustrations of the ways in which these data tables can be used in connection with storage battery locomotive haulage. They will be found useful, also, in determining the motor capacity for locomotives, and

TABLE III.

STORAGE BATTERY HAULAGE

Total loads in Tons that can be hauled by a 100 kilowatt-Hour Storage Battery 100 feet per minute when the Locomotive Efficiency is 100%.

Grade.	Discharge Rate	Friction Loads in Lbs. per Ton.							
		50	40	35	30	25	20	15	10
Level	1 Hr.	488	605	690	808	973	1210	1615	2420
	2 "	288	358	410	478	575	718	975	1430
	3 "	222	276	315	368	444	553	735	1104
	4 "	179	223	255	297	358	446	593	890
	5 "	155	193	222	258	310	386	514	770
	8 "	111	138	158	184	222	276	368	554
½%	1 Hr.	405	488	540	605	690	808	973	1210
	2 "	240	288	320	358	410	478	575	718
	3 "	185	222	246	276	315	368	444	553
	4 "	149	179	199	223	255	297	358	446
	5 "	129	155	173	193	222	258	310	386
	8 "	93	111	124	138	158	184	222	276
1%	1 Hr.	348	405	443	488	540	605	690	808
	2 "	206	240	263	288	320	358	410	478
	3 "	159	185	202	222	246	276	315	368
	4 "	128	149	163	179	199	223	255	297
	5 "	111	129	141	155	173	193	222	258
	8 "	79	93	101	111	124	138	158	184
1½%	1 Hr.	304	348	375	405	443	488	540	605
	2 "	180	206	221	240	262	288	320	358
	3 "	138	159	171	185	202	222	246	276
	4 "	112	128	138	149	163	179	199	223
	5 "	97	111	119	129	141	155	173	193
	8 "	69	79	85	93	101	111	124	138
2%	1 Hr.	270	304	325	348	375	405	443	448
	2 "	160	180	192	206	221	240	262	288
	3 "	123	38	148	159	171	185	202	222
	4 "	100	112	120	128	138	149	163	179
	5 "	86	97	104	111	119	129	141	155
	8 "	62	69	74	79	85	93	101	111
2½%	1 Hr.	243	270	284	304	325	348	375	405
	2 "	143	160	168	180	192	206	221	240
	3 "	111	123	144	138	148	159	171	185
	4 "	90	100	104	112	120	128	138	149
	5 "	77	86	94	97	104	111	119	129
	8 "	56	62	65	69	74	79	85	93
3%	1 Hr.	220	243	257	270	284	304	325	348
	2 "	131	143	152	160	168	180	192	206
	3 "	101	111	117	123	144	138	148	159
	4 "	81	90	94	100	104	112	120	128
	5 "	71	77	82	86	94	97	104	111
	8 "	51	56	58	62	65	69	74	79
3½%	1 Hr.	203	220	231	243	257	270	284	304
	2 "	120	131	137	143	152	160	168	180
	3 "	92	101	106	111	117	123	144	138
	4 "	75	81	85	90	94	100	104	112
	5 "	65	71	74	77	82	86	94	97
	8 "	47	51	53	56	58	62	65	69
4%	1 Hr.	188	203	212	220	231	243	257	270
	2 "	111	120	125	131	137	143	152	160
	3 "	85	92	96	101	106	111	117	123
	4 "	69	75	78	81	85	90	94	100
	5 "	60	65	68	71	74	77	82	86
	8 "	43	47	48	51	53	56	58	62

generator capacity necessary for operating locomotives upon trolleys or third-rail systems. On account of the efficiency of locomotives varying with many conditions, the data tables have been based upon that efficiency being 100 per cent.

Tables I., III. and IV. show clearly the advantage of reducing the frictional resistance of the train as much as possible. In most industrial plants the tracks can be made practically level and as friction forms a greater part of the load which the locomotive has to haul, the battery capacity necessary depends upon

TABLE IV.

HAULAGE DATA.

Kilowatts required to move 100 Tons 100 feet per minute under different friction loads and on various grades when the Locomotive Efficiency is 100%.

Grade.	Frictional resistance in pounds per ton on level track.							
	50	40	35	30	25	20	15	10
Level	11.3	9.1	7.9	6.8	5.7	4.6	3.4	2.3
½%	13.6	11.3	10.2	9.1	7.9	6.8	5.7	4.6
1%	15.9	13.6	12.5	11.3	10.2	9.1	7.9	6.8
1½%	18.1	15.9	14.7	13.6	12.5	11.3	10.2	9.1
2%	20.4	18.1	17.0	15.9	14.7	13.6	12.5	11.3
2½%	22.6	20.4	19.4	18.1	17	15.9	14.7	13.6
3%	24.9	22.6	21.5	20.4	19.4	18.1	17	15.9
3½%	27.2	24.9	23.8	22.6	21.5	20.4	19.4	18.1
4%	29.4	27.2	26	24.9	23.8	22.6	21.5	20.4
4½%	31.8	29.4	28.3	27.2	26	24.9	23.8	22.6
5%	34	31.8	30.5	29.4	28.3	27.2	26	24.9
5½%	36.3	34	32.9	31.8	30.5	29.4	28.3	27.2
6%	38.5	36.3	35.2	34	32.9	31.8	30.5	29 4

the frictional resistance of the train. Every means which tends to reduce this item of energy consumption adds rapidly to the radius of action of the locomotive and to the efficiency of the haulage system.

Table V gives the kilowatt hours required to charge a battery to move one ton 100 feet, when discharging at various rates and hauling trains against various friction loads and grades, the energy efficiency of battery on eight hour discharge rate being 75% and the locomotive efficiency being 100%.

TABLE V.

Kilowatt Hours required to charge a battery to move one ton 100 feet, when discharging at various rates and hauling trains against various friction loads and grades, the energy efficiency of battery on 8-hour discharge rate being 75% and the locomotive efficiency being 100%.

Grade	Discharge Rate.	Friction Load in Lbs. per ton.							
		50	40	35	30	25	20	15	10
Level,	1 Hr.	.004570	.003670	.003210	.002755	.002285	.001840	.001290	.000919
	2 "	.003865	.003110	.002715	.002325	.001935	.001556	.001092	.000777
	3 "	.003350	.002695	.002355	.002020	.001680	.001350	.000947	.000674
	4 "	.003100	.002495	.002180	.001870	.001552	.001250	.000877	.000624
	5 "	.002875	.002310	.002018	.001730	.001437	.001157	.000868	.000577
	8 "	.002512	.002020	.001765	.001513	.001256	.001011	.000758	.000505
½%	1 Hr	.005475	.004570	.004115	.003670	.003210	.002755	.002285	.001840
	2 "	.004630	.003865	.003480	.003110	.002715	.002325	.001935	.001556
	3 "	.004020	.003350	.003020	.002695	.002355	.002020	.001680	.001350
	4 "	.003720	.003100	.002790	.002495	.002180	.001870	.001552	.001250
	5 "	.003440	.002875	.002585	.002310	.002018	.001730	.001437	.001157
	8 "	.003010	.002512	.002261	.002020	.001765	.001513	.001256	.001011
1%	1 Hr.	.006400	.005475	.005020	.004570	.004115	.003670	.003210	.002755
	2 "	.005415	.004630	.004250	.003865	.003480	.003110	.002715	.002325
	3 "	.004695	.004020	.003680	.003350	.003020	.002695	.002355	.002020
	4 "	.004350	.003720	.003410	.003100	.002790	.002495	.002180	.001870
	5 "	.004020	.003440	.003155	.002875	.002585	.002310	.002018	.001730
	8 "	.003520	.003010	.002760	.002512	.002261	.002020	.001765	.001513
1½%	1 Hr	.007325	.006400	.005940	.005475	.005020	.004570	.004115	.003670
	2 "	.006200	.005415	.005020	.004630	.004250	.003865	.003480	.003110
	3 "	.005370	.004695	.004360	.004020	.003680	.003350	.003020	.002695
	4 "	.004970	.004350	.004035	.003720	.003410	.003100	.002790	.002495
	5 "	.004600	.004020	.003730	.003440	.003155	.002875	.002585	.002310
	8 "	.004025	.003520	.003265	.003010	.002760	.002512	.002261	.002020
2%	1 Hr.	.008250	.007325	.006835	.006400	.005940	.005475	.005020	.004570
	2 "	.006975	.006200	.005780	.005415	.005020	.004630	.004250	.003865
	3 "	.005060	.005370	.005010	.004695	.004360	.004020	.003680	.003350
	4 "	.005600	.004970	.004640	.004350	.004035	.003720	.003410	.003100
	5 "	.005180	.004600	.004300	.004020	.003730	.003440	.003155	.002875
	8 "	.00454	.004025	.003760	.003520	.003265	.003010	.002760	.002512
2½%	1 Hr.	.009145	.008250	.007840	.007325	.006835	.006400	.005940	.005475
	2 "	.007740	.006975	.006635	.006200	.005780	.005415	.005020	.004630
	3 "	.006710	.006050	.005750	.005370	.005010	.004695	.004360	.004020
	4 "	.006210	.005600	.005330	.004970	.004640	.004350	.004035	.003720
	5 "	.005730	.005180	.004925	.004600	.004300	.004020	.003730	.003440
	8 "	.005030	.004540	.004315	.004025	.003760	.003520	.003265	.003010
3%	1 Hr.	.010075	.009145	.008700	.008250	.007840	.007325	.006835	.006400
	2 "	.008520	.007740	.007350	.006975	.006635	.006200	.005780	.005415
	3 "	.007380	.006710	.006375	.006050	.005750	.005370	.005010	.004695
	4 "	.006840	.006210	.005910	.005600	.005330	.004970	.004640	.004350
	5 "	.006330	.005750	.005455	.005180	.004925	.004600	.004300	.004020
	8 "	.005540	.005030	.004775	.004540	.004315	.004025	.003760	.003520
3½%	1 Hr.	.010950	.010025	.009510	.009145	.008700	.008250	.007840	.007325
	2 "	.009275	.008520	.008130	.007740	.007350	.006975	.006635	.006200
	2 "	.008040	.007380	.007050	.006710	.006375	.006050	.005750	.005370
	4 "	.007440	.006840	.006520	.006210	.005910	.005600	.005330	.004970
	5 "	.006890	.006330	.006040	.005750	.005455	.005180	.004925	.004600
	8 "	.006030	.005540	.005280	.005030	.004775	.004540	.004315	.004025
4%	1 Hr.	.011870	.010950	.010540	.010075	.009610	.009145	.008700	.008250
	2 "	.010050	.009275	.008920	.008520	.008130	.007740	.007350	.006975
	3 "	.008710	.008040	.007730	.007380	.007050	.006710	.006375	.006050
	4 "	.008065	.007440	.007160	.006840	.006520	.006210	.005910	.005600
	5 "	.007465	.006890	.006620	.006330	.006040	.005750	.005455	.005180
	8 "	.006530	.006030	.005795	.005540	.005280	.005030	.004775	.004540

From this table the cost of haulage by storage battery locomotives under the given conditions can be approximately determined. As the energy efficiency and storage capacity vary with different conditions of electrolyte and with the cycle of voltage through which the battery is charged and discharged this table cannot be considered accurate for all cases. A complete review of each individual case is necessary for determining the exact energy input of a battery for a given duty.

Motors.

The motors for storage battery locomotives should be series wound and properly proportioned and geared for the duty of the locomotive. The essential requirements of these motors have to do chiefly with control and will be discussed further under that subject.

Control.

Industrial locomotives may be divided into three classes, viz., those used for hauling other cars; those in which the load is carried upon the locomotive, and those used for both carrying and hauling. In the case of a locomotive used only for hauling other cars, the maximum tractive effort which it can exert depends upon the material and condition of the wheels and rails, but with either of the other two classes mentioned the maximum tractive effort depends upon the load carried by the locomotive.

The best method of control for an electric storage battery locomotive, like the equipment, depends also upon the duty and kind of service the locomotive has to render. In some instances it is necessary to equip the locomotive with every appliance for charging the batteries as well as for controlling the speed, while in others the charging apparatus may be installed at a charging station and the locomotive equipped with means for speed control only.

Speed control may be effected by grouping the battery cells; by use of a variable resistance, or by a combination of cell grouping and variable resistance. When two or more motors are used variation in speed may be had by series and parallel connections of the motors.

The character of storage batteries renders it unwise to charge or discharge them more rapidly than at a given safe rate, or beyond a given cell terminal voltage. This makes it necessary to provide circuit breakers or other protective devices to prevent these limits being exceeded. In some instances the motors and battery have been designed so that when the battery is deliver-

ing its maximum safe current, the drive wheels will be almost on the point of slipping and any greater current causes the wheels to slip, thus relieving the motors and battery. Such an equipment, if at all desirable can be safely used upon locomotives employed for hauling only, and where the battery and motors are correctly proportioned and grouped for such results. Locomotives equipped with batteries as an auxiliary source of energy supply can seldom carry sufficient battery capacity for slipping the drivers, and those locomotives used for carrying have such a variable maximum tractive effort that protection by wheel slippage is out of the question. For a general equipment, then, it seems best to employ an overload and voltage limit circuit breaker for discharging the battery and an overload and underload circuit breaker for charging it.

For uniform life all of the battery cells should be worked alike. To accomplish this, the number of cells in series must be continually halved to make the various groupings. By using a maximum of four groups, three speeds may be had without altering the motor connections, and by connecting the motors in series and parallel a fourth speed is possible. With two motors in parallel and three battery groupings the relative speeds are: $\frac{1}{4}$, $\frac{1}{2}$ and 1, corresponding respectively to battery grouping of four groups in parallel, two groups in parallel and two in series, and all four groups in series. By throwing the motors in series and four groups of cells in parallel, a relative speed of $\frac{1}{8}$ is obtained.

A very satisfactory arrangement is one in which the motors are connected permanently in parallel, the battery is divided into four groups and a variable resistance is used in grading each of the three speeds available by battery grouping. Without a variable resistance for grading the starting effect, the gears, motors and battery all receive severe strains when the terminal voltage is suddenly doubled.

In determining the best equipment to use, two classes of service are frequently presented. In one class the locomotive is called upon to exert a large effort at a slow speed or a small effort at a higher speed. In the other class, the effort of the locomotive is practically the same at all speeds. In the first class the total current capacity of the two motors in parallel and the cells in four groups should be equal. With the motors and batteries thus connected, the maximum effort would be obtained and at each successive grouping of the cells a lesser effort at a pro-

portionately higher speed would be had. In the second class the batteries connected all in series should have a current capacity equal to that of the two motors in parallel. With this arrangement the maximum effort would be obtained at the maximum speed and with other groupings of the cells the same effort at lesser speed would be possible. For the same maximum effort the motors and battery in the first class may be only one-fourth the capacity of those in the second class.

The illustrations, Figs. 1, 2 and 3, are views of different storage battery locomotives at work. The locomotive shown in Fig. 1 is arranged so that the battery may be charged and the locomotive operated at the same time by current collected by the trolley. Over portions of the track a trolley wire is not permissible and upon such portions the battery is used for operating the locomotive. Ordinarily, the battery is charged only while operating on the trolley line. The batteries are connected permanently in series and speed control is effected by variable resistance as in ordinary street railway service. A separate charging resistance and switch is provided.

The locomotive shown in Fig. 2 is equipped with a 20 k.w. storage battery as its only source of energy supply. It is so arranged that the same resistance and controller that are employed for speed control are also used for charging the battery. Charging plugs are placed at convenient points and the locomotive service is so arranged that after ten hours' operation the battery still has 65 per cent. of a full charge available. The batteries are connected permanently in series. The locomotive and battery together weigh 7½ tons.

The illustration in Fig. 3 is of a 12-ton, double truck locomotive equipped with a 25 k.w. hour battery. Each truck has both its axles driven by a single motor through flexible connecting links. The batteries are connected in four groups, and speed control is effected by battery grouping only. A separate charging switch and resistance are employed, and charging is done at stations provided for the purpose.

From results obtained through both calculation and experience it appears that the electric storage battery when properly designed for its duties can be employed with greater advantages and economy than any other known form of energy storage supply for industrial locomotives. It is probable that somewhat special elements will be required as it seems impossible to secure the necessary life and strength for the plates without making

them especially heavy. This is not ordinarily a disadvantage with industrial locomotives as the weight is necessary for traction. As in all other problems in which energy and power have to be considered, the results obtained with storage batteries will be exactly those for which provision has been made.

Discussion.

Mr. Edgar H. Berry:—I concur fully in the opinion expressed by the author as to the special suitability of the storage battery for use on industrial locomotives. Its convenience, safety and ease of maintenance have been so clearly explained that comment on these points seems unnecessary. I wish, however, to take exception to the statement on page 968, which implies a very material reduction in the battery efficiency when discharging at a high rate. As a matter of fact, a storage-battery maintains its efficiency very well over a considerable range of loads. I will have occasion to refer to this further in connection with one of the tables presented in the paper.

Durability and depreciation have not been touched upon at all. Unfortunately, or perhaps I should take the point of view of the user and say fortunately, I am not able to say how long it takes to wear one of these locomotives out. The oldest one I know of has been in constant operation for over four years, and the original battery-plates are still doing their full duty. In his book on storage batteries Mr. E. J. Wade figures the depreciation on stationary cells by assuming a life of three to six years for positive plates, and of five to ten years for negative plates. Judging from the case I have in mind, a good battery of the type usually employed for stationary work will not suffer any reduction in its useful life when used on an industrial locomotive. Even when the plates reach a point at which it will be economical to replace them, the balance of the locomotive should still be perfectly serviceable for a further indefinite period.

An arrangement is mentioned on page 980 for charging from a trolley or third rail while the locomotive is in use. If this has proved successful it would be very interesting if we could hear just how it was done. Unless the feeders were large enough to keep the voltage at the locomotive practically constant, it would seem as if the charging current would fluctuate between undesirably wide limits. The current does not vary directly as the impressed voltage, but approximately as the difference between this voltage and the voltage of the battery. I have taken readings during a charge that have shown a change of over 13 per cent. in the current for a change of 1 per cent. in the voltage. The battery in question consisted of 44 cells, the normal charging rate being 20 amperes. At a certain state of the charge 105.5 volts were needed to maintain the normal rate, but an increase of four volts, making a total of 109.5 gave a current of 30 amperes. A jump of four volts on a 110-volt trolley circuit would be nothing unusual, but a charging current of one and one-half times the normal would be highly undesirable near the end of the charge, when it would cause wasteful gassing, and probably injurious heating.

To ensure the selection of a suitable battery it would seem necessary to add one more condition to those given at the top of page 971. This additional requirement to be worded "and that

the permissible charging rate be high enough to permit of charging in the time available for that purpose." This is highly important, for if the battery is worked at the one-hour rate, which is usually about four times the normal charging rate, the charging time must be four times as long as the discharging time, or four hours. If this is not available, a larger battery, or two sets of battery, must be employed. In many cases the larger battery would give a cheaper, simpler and more desirable solution. Of course if the service is very heavy an extra removable battery may become absolutely essential.

Passing now to the tables, I find a slight discrepancy between Table I. and the example given to illustrate its use. If the figures in the table are intended to apply to the total load, including the locomotive, the latter is charged with the same friction loss as the cars, and then in addition it is afterwards charged with its own efficiency loss. By adding one more column to the table, giving the kilowatt hours needed to move one ton 100 feet up the various grades with a friction of zero pounds per ton, it would be possible to determine separately the work of lifting the locomotive, and of hauling the cars. The sum of these two, divided by the efficiency of the locomotive would give the true result. Under the efficiency I understand the ratio between the energy effective at the wheels, and the energy developed at the battery terminals.

Assuming the coefficient of traction to be one-fifth, the error in the table as it now stands runs from two and one-half per cent. at a friction loss of 10 pounds per ton, to twelve and one-half per cent. at 50 pounds per ton. It is, however, all on the safe side.

Of course I do not know what make of battery was used as a basis for Table II., but the discharge and capacity at the higher rates seem too large. For instance, the one hour rate in amperes is usually taken at four times the eight hour rate, making the output in ampere-hours for a one hour discharge, one-half of that for an eight hour discharge. But the extra $C^2 R$ loss at the higher rate cuts down the voltage, and consequently the watt-hours. Their value for a one-hour rate should therefore be less than 50 per cent. of the value for an eight hour rate. The table gives 55 per cent., making the kilowatt hours for the one-hour rate over 10 per cent. higher than the figures I have been in the habit of using.

In connection with Tables III. and IV., mention is made on page 974 of the importance of cutting down the friction loss of the cars as much as possible. To emphasize this I may point out that poor bearings in the cars may easily halve the load which a locomotive can haul on a level track. Or, putting it in another way, they may necessitate the use of two locomotives instead of one.

Table V. has puzzled me somewhat, but in talking it over with Mr. Sessions this morning I find that he bases it on an assumption which seems to me to be very unfair to the locomo-

tive. If we accept this table we must admit that at a high discharge rate a battery is completely discharged at the end of the number of hours corresponding to that rate. This of ocurse is not a fact, for when a battery has reached the point at which it can no longer maintain the high rate of discharge, it can still discharge for a further period at a lower rate; the sum of the watt-hours at the different rates, being equal to the watt-hours used in charging, less the unavoidable loss due to a transformation of energy. If the discharge is stopped when the high rate can no longer be maintained, it is only necessary to put back as many watt-hours as were taken out, plus the transformation loss. Just what this loss is at different discharge rates I am not prepared to say, and I do not know that any definite data in regard to this point have ever been published. Perhaps our committee on engineering data can unearth some information about it. But in any event I feel safe in saying that the efficiency at a one hour rate is nearer to 70 per cent. than to 41 per cent., which is the figure used in the table.

Up to this point all the calculations have been made in kilowatts and in kilowatt-hours, the exact current and voltage being immaterial as long as their product had a suitable value. But now in selecting a specific motor and suitable gears the battery voltage becomes important, and this in turn should preferably be such that it will be possible to charge directly from some available source of supply. Furthermore, it is highly desirable to use standard commercial sizes of batteries and motors, and these must be so chosen that the combination fits the original assumptions as closely as possible. Exact agreement could of course only occur by chance, and I have found it most desirable to select a gear ratio which will fit the ampere torque curve of the motor, and to allow the speed at a given load to differ slightly from the original assumed value, according to the degree of accuracy with which the battery and motor actually employed approximate to their calculated sizes.

The use of a resistance for controlling the speed does not seem justifiable on a storage-battery locomotive. Aside from the actual waste of power in the resistance, extra time is needed for charging, and the battery capacity is virtually reduced. Even when only a single motor is employed, two groups of cells and a split series field give four speeds, which seem to be ample to meet all requirements. The split field is arranged so that the two halves can be thrown in series or in parallel with each other. With two motors the possible combinations are further increased as the motors themselves can be connected in series and parallel arrangements.

If the resistance is used for starting only, the power wasted in it may of course be negligible, but with an ignorant or thoughtless operator the loss may assume larger proportions. The term "fool proof" was unknown before electricity came into general use, but the public having once discovered that apparatus *can* be

so built, immediately uses it on the assumption that it *is* so built, and the locomotive designer has no choice but to fall in line.

Another safeguard against abuse is pointed out at the bottom of page 978. The locomotive can be so proportioned that the wheels will slip before either the motor or the battery is seriously overloaded. This arrangement has proved highly satisfactory in actual use, and it seems to be the best and simplest method of protection that can be devised. It provides a safety valve that cannot get out of adjustment, and that cannot be tampered with in any way short of piling dead weight on the locomotive.

A question may be raised as to the desirability of a voltage limit circuit-breaker. This, I take it, is to open the circuit when the battery voltage falls below the allowable limit, thus calling attention to the necessity for an immediate recharge. Suppose, now, that this opens when the locomotive is some distance from the charging station. To get back the locomotive must either be hauled, or else the circuit-breaker must be held in. The average operator I think will choose the latter method. But running a locomotive while holding in a circuit breaker is not convenient, and the obvious remedy is to tie in the arm. This leads easily to the next step of having the arm tied in continually, when the locomotive will be in the dangerous situation of being supposedly protected by a device which actually is inoperative. On the other hand it is a simple matter to make the operator understand that he must recharge as soon as the voltmeter needle falls to a certain point.

An underload and overload circuit-breaker in the charging circuit seems to be very desirable, but it must not be forgotten that the underload release may fail to protect if the voltage of the charging line fluctuates. A very slight increase in the line voltage may continuously maintain the current above the point at which the underload release operates. If, however, the conditions are such that the line voltage is constant, the underload release affords an excellent protection.

In speaking of a locomotive called upon for a large effort at a low speed, and for a smaller effort at a higher speed, the paper suggests connecting the cells in four parallel groups for the first case, and connecting them all in series for the second case. I would like to inquire what safeguard is provided to prevent the operator from throwing all the cells in series, even when the higher effort is required. This would take four times the permissible current from the battery, but would not overload the motor, and therefore would neither slip the wheels, nor open the circuit-breaker.

The employment of extra heavy battery plates, which is mentioned at the close of the paper as a possible necessity has many disadvantages, and in the light of past experience it hardly seems called for. The additional expense of special plates would add materially to the cost of the locomotive, and the advantages to be derived are open to serious question. I would not recommend

the use of a light vehicle battery on a locomotive, but the type ordinarily used for stationary work seems to possess ample strength. If more weight is necessary to give adhesion, pig iron will be just as serviceable as battery plates costing 30 to 40 cents per pound. Or if dead weight is to be eliminated at all costs, a larger battery might be employed, giving more reserve capacity, and requiring less time for a normal charge.

While weight is of course necessary to give adhesion, it is well to bear in mind that even a heavy locomotive may be deficient in hauling power unless all, or practically all the weight is on the drivers. All other weight in the locomotive means a corresponding reduction in the load that can be hauled. Assume for example a ten ton locomotive, in which all the wheels are drivers, and which can just haul a load of ten tons up a certain hill without slipping the wheels. If only half the weight of this locomotive were on the drivers, it could just climb the hill alone, without load.

In conclusion, I wish to express my appreciation of the paper before us. Industrial locomotives are new, comparatively speaking, and I believe that the present paper is the first one on this subject to be presented before this INSTITUTE. If such a pioneer paper possesses any interest at all it is bound to start a discussion in which differences of opinion will be in evidence. I have endeavored to show my interest in the paper by finding as much fault as possible, and I trust that some of the other members will show their interest in the discussion in the same way.

MR. SESSIONS:—In reply to the question of protection by circuit-breaker when the batteries are connected in either series or parallel, I would say that the circuit-breaker, if especially adapted for the work, will open so as to protect the batteries when the locomotive develops a smaller effort at higher speed. The circuit-breaker for this purpose may appear complicated at first glance, but it differs from the ordinary overload circuit-breaker only in necessitating several wires running to it instead of the ordinary two. The tripping-magnet is wound in as many sections as there are groups of cells and each group of cells is connected in series with one of these sections. The sections of the tripping-magnet coil, therefore, are in series or parallel in the same way that the cells are, and for the same current drawn from one group of cells the ampere-turns upon the tripping-magnet are always the same.

I should like to take up further some of the points touched on by Mr. Berry. I admit that the example illustrating Table I. is not accurately solved and that it errs exactly as Mr. Berry states, but an error of $2\frac{1}{2}$ per cent. is hardly worth calculating for the general run of storage-battery problems, and a slight allowance in the locomotive efficiency will compensate the inaccuracy. As yet the refinements of the art are not such as to demand calculations within that limit. Table I., itself, is absolutely correct and will be found very convenient.

With regard to the charging rate for storage-batteries, and also with regard to Table II., in which the one-hour discharge capacity is given as 55 per cent, of that for eight hours, it is a fact that both of these features depend radically upon the method of forming the plates and I must maintain that the figure is accurate for batteries suitable for industrial locomotives. Certain formations of plates will not stand the high discharge that others will.

As to the efficiency of the storage-battery locomotive, I wish to take a stand for conservatism in this respect—perhaps there is a slight ambiguity in assuming that a battery is entirely discharged at any one rate, at a high rate especially, but such an assumption is necessary where the locomotive duty is unknown. In Table V. I have assumed that the battery is fully charged when starting to discharge, and that it is discharged to the safe limit without any time given for recuperation. I have stated in reference to Table V ,

> " As the energy efficiency and storage capacity vary with different conditions of electrolyte and with the cycle of voltage through which the battery is charged and discharged, this table cannot be considered accurate for all cases."

In each case where the battery of a locomotive is to be charged and discharged in repeated cycles, it will be necessary to review an entire day's work in order to get a complete and accurate lot of data for determining the energy required for that locomotive.

The use of resistance for starting and controlling storage-battery locomotives has proved to be a very satisfactory arrangement, and the energy losses in the resistance are not considerable enough ordinarily to be an objection, when consideration is given to the cost of maintenance and the severe strains put upon various members when the motor terminal-voltage is instantly doubled.

As to charging the battery while the line is supplying current for operating the locomotive, I will say that this has been proved highly successful and economical in several instances. It is probable that a battery does not have so long a life when it is thus used, as there is a temptation always to charge at a high rate, but, as our compressed air friends would say, " efficiency is not alone the ratio of the energy output to the energy input." It depends upon the results in the work for which the battery is designed.

MR. ELMER A. SPERRY:—I would like to call attention to the rapidly growing demand for locomotives of this nature, the nature described in this paper. I believe that they are going to fill a want that has been attempted on the part of our compressed air friends. Two or three years ago I was called upon to make some comparative tests of locomotives of this nature and those operated by compressed air, and, in conformity with the last remark of Mr. Sessions, it would seem that our compressed air friends are not strong in the matter of efficiency. That is, they do not rely very materially on this factor. The

results of calculations that were made at the time to which I refer might be interesting to you, as pointing not only to the matter of efficiency but also as comparing the weights necessary to be carried in the two instances to do the same work. We usually think the storage-battery, being made of lead, is an extremely heavy and cumbersome affair to carry the energy that it is enabled to develop and supply. Now, as a matter of fact, the compressed air, when re-heated—not taking into consideration the weight of the re-heating apparatus—but simply considering the weight of the compressed air drum, and in this instance, as I remember it, the pressure of the air was something like 3700 pounds to the square inch—we found that the amount of energy capable of being supplied per ton of compressed air, together with its tank, as compared with the ton of storage battery all told, was in the neighborhood of 23¼ per cent. only, in the case of compressed air, less than one-quarter. And, as over against this consideration, we have another. That is, the compressed air factor is running down as it is exhausted. For instance, when the compressed air is half exhausted, the pressure is half gone; when three-quarters exhausted, the pressure is only one-quarter of the initial pressure; whereas, in the case of the storage-battery, the curve is almost ideal. The battery, when we have exhausted it one-half is still almost at the same pressure as when we started: when exhausted three-quarters it is still nearly the same, the curve, as you remember, being almost horizontal. I think, as I said before, that there is a gradually widening field for the storage battery car.

[COMMUNICATED AFTER ADJOURNMENT BY EDGAR H. BERRY.]

The writer has taken up the question of battery efficiencies at different discharge rates with a well-known company which has had a wide experience in the manufacture and maintenance of storage-batteries, and whose records contain a considerable fund of information in regard to the actual performance of its cells.

This company states that "assuming the efficiency of 75 per cent. for the 8-hour charge and discharge rates to be correct, the amount of energy required to recharge after a discharge at the 5, 3 or 1-hour rate, would be exactly proportionate to the amount taken out—so long as the charging was done at the normal rate."

On this basis all the figures in Table V., excepting those applying to the 8-hour rate, should be eliminated, and the figures for the 8-hour rate should be taken as applying to the 8-hour, 1-hour and all intermediate rates.

The writer does not for a moment wish to advocate the deliberate selection of a high discharge rate, but he does insist that the objections to such a course do not arise from an increase in the watt-hours per unit of work, necessary for charging. The penalties imposed by a high discharge rate are similar to those incurred when any piece of apparatus is worked very near its ultimate limit of endurance. A high discharge rate means a low factor of safety for carrying an overload, a very low reserve

storage capacity, and a considerable increase in the risk of injury to the plates when handled by unskilled persons. These are the considerations that must be set against the increased cost of the larger battery, in determining the proper size to give the highest ultimate commercial efficiency.

[COMMUNICATED AFTER ADJOURNMENT BY F. L. SESSIONS.]

In commenting upon Mr. Berry's supplementary note, I would say that I desire to give the storage-battery credit for whatever efficiency it may have. Table V. is correct as it stands for the conditions assumed. Mr. Berry seems to overlook those conditions, and to distort the data given by assuming other conditions for the sake of giving the storage-battery a better face. It is difficult in compiling data to choose that which will be convenient for every case, and that which is not applicable should, of course, not be used.

The statement of a battery manufacturer, which Mr. Berry quotes, is probably correct for the conditions assumed. In this connection I would say that I should be more than delighted to learn the name of any battery manufacturer who will guarantee either efficiency or capacity, or assume any responsibility for his products after they leave his factory.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

PREDETERMINATION IN RAILWAY WORK.

BY F. W. CARTER.

A presentation, with examples, of an analytical method of treatment of train-movement problems based upon the assumption that, within the working range of ordinary railway motors, the relations between tractive effort and current may be represented by a straight line, and between speed and current by a hyperbola.

I.—INTRODUCTORY.

To the steam engineer it must occasion some surprise to observe how closely the performance of an electric train can be predicted from the knowledge gained by a few stand tests on its motors. When the particulars of the problem are fully known, it is possible to determine how the motor will behave dynamically, when put to a particular service, with almost as great a degree of accuracy as its conduct can be observed. This possibility arises from the simplicity and definiteness of the circumstances on which the performance of the motor depend. At any particular voltage the torque and speed corresponding to a particular current are definite and can be determined from stand tests, whilst the change in these quantities with variation of voltage can be computed. The relation between torque and speed is all that one need know about the motor in order to determine its dynamical effect on the train. Knowing the frictional resistance to motion at any particular speed, we can, from the torque and mass moved, determine the rate of change of speed, and hence the interval of time required to produce a given small change in speed, and so, by a process of point to point construction, obtain the speed-time curve, from which to determine the times, distances etc., which are the ultimate ends of the calculation. Though somewhat long and tedious, this is the natural and sagacious method of attacking the problem. It is the method of the pioneer, which is applicable to any speed-torque curve whatever.

The method of the present paper applies only to the ordinary continuous current railway motor, or to motors having similar characteristics. It shows how some of the machine tools of analysis can be employed in the treatment of the problem, for the purpose of obtaining the required results without having to build all the intermediate bridges afresh for every new case that arises.

The most general problems in the subject present no great difficulties to the method, which nevertheless takes account of all the circumstances of the case. Given the profile of a road, with the stops, curves, etc., and the particulars of the train and its equivalent, also the mean voltage and train friction, we can lay out a time table for the train, find the energy it requires, or deter-

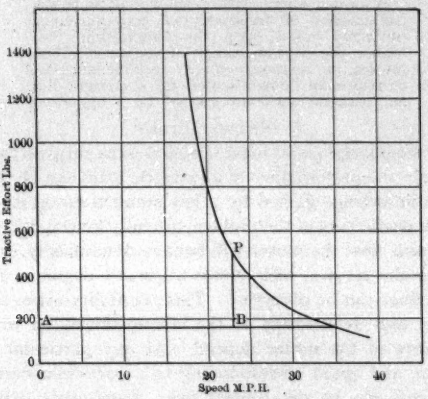


FIG. 1.

mine the motor losses. Such a problem treated by the usual method would be very long and consume a great deal of curve paper, whilst the method herein described obtains the solution easily and completely without it being necessary to plot a single curve.

The paper first discusses the kinematics of the subject; afterwards it is shown how to determine the energy used and the motor losses. Illustrative examples follow the general treatment.

The information necessary in employing the method is given in the form of curves and simple equations, which can be used without reference to the underlying analysis.

II.—Principles of Method.

We have stated that when the speed-time curve for any equipment and schedule has been found, we can easily determine all the circumstances of the run, and have indicated how the speed-time curve for the train can be computed from the speed-tractive-effort curve of the motors. Let Fig. 1 represent the speed-tractive-effort curve for a motor. Let O A be the tractive force required to overcome train resistance, so that, at the speed represented by the point P, the accelerating force per motor is P B. Let Fig. 2 be the speed-time curve deduced from Fig. 1 for a particular weight of train, when the train resistance per motor is O A. If now we draw a number of such speed-time curves for different values of train resistance O A, we shall have provided ourselves with the means of solving any problem whatever involving this train and equipment, having simply to copy the required portion of the appropriate speed-time curve. If we wish to handle a

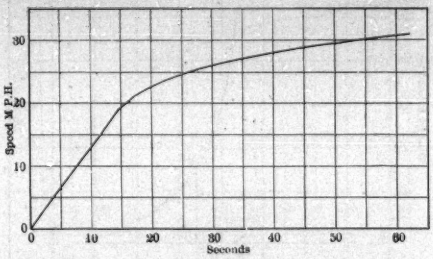


Fig. 2.

problem involving several grades or varying train resistance, we can do so; we continue for the requisite distance on the curve corresponding to the first grade, then, on change of grade step to the appropriate curve at the same speed, and copy the requisite portion of this curve, and so on.

Suppose now we halve the gear reduction ratio of the motors. This will double the speed for any current and halve the tractive effort, giving us Fig. 3, which is exactly the same as Fig. 1, except that the scales are altered. Suppose there is only half the weight of train and half the train resistance per motor; then at any point P we have half the accelerating force acting on half the mass, thus producing the same rate of acceleration as in the problem of Figs. 1 and 2. Since, however, the velocity is doubled everywhere, it will require double the time to run between a pair of points in Fig. 3, as compared with the corresponding points of

Fig. 1. Thus the speed-time curve for this case, shown in Fig. 4. is exactly the same as Fig. 2, except that the scales of time and speed are both halved. It follows then that the system of speed-time curves supposedly drawn to correspond to the equipment of Figs. 1 and 2, can be used for other equipments, by proper change in the scales of time and speed. As a matter of fact, as we shall show, such a system, drawn for a particular equipment, will apply to any equipment whatever; the only difficulty in the use of such a system occurs in determining which curve, and what scales of ordinate and abscissa are to be employed in a particular case.

The general shape of the motor characteristic is reflected in the general shape of the speed-time curves, whilst the fact that there are three quantities to be determined in any particular problem

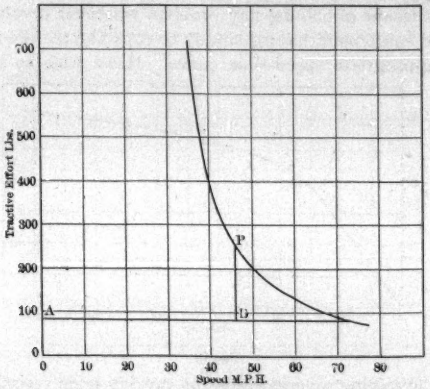


FIG. 3.

implies that the affecting circumstances are dynamically equivalent to three only. These may be taken as: (1) The motor equipment, represented by the speed-tractive-effort curve, and including the gear and size of wheels, besides the true characteristic of the motor at the voltage used. (2) The train driven by the motors, represented by its effective weight, and including the apparent additional weight due to the effect of rotary inertia. (3) The train resistance, including that due to grade as well as frictional and wind resistances. From one point of view we may describe the object of the present paper as seeking to determine the most convenient means of combining these three circumstances in order to obtain a workable solution of the dynamical problem of train motion on the lines indicated above.

III.—Notation.

The suffix 1 is used to distinguish the value a quantity has during the time of acceleration on resistance. The suffix 2 distinguishes a quantity during speed-curve running. The suffixes 3 and 4 refer similarly to coasting and braking respectively. The suffix 0 marks a constant of the same dimensions as the quantity represented by the letter to which it is attached. A dashed letter signifies the value that a quantity would take if free running speed were attained under the conditions supposed. A letter without distinguishing mark is used for the current value of a quantity. The signification of the several letters will be explained as they are met with.

IV.—General Dynamics.

Let w be the effective weight of the train per motor, including the apparent addition due to inertia of rotating parts. Let s be

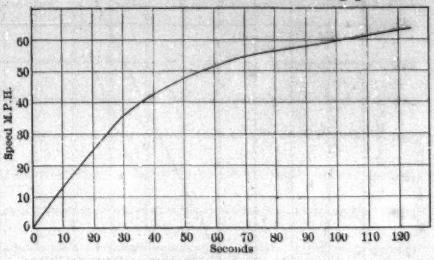


Fig 4.

the speed at time t, F the tractive force of the motor and F^1 the resistance to traction, composed of frictional resistance and grade resistance. Then, the forces being in gravitational units and g being the value of the acceleration due to gravity, the general equation of motion for the train is

$$w \frac{d s}{d t} = (F - F^1)\, g \qquad (1)$$

During the time of acceleration on resistance, we may take F and F^1 as uniform, giving $d s/d t$ constant, $= a_1$ where

$$w a_1 = (F_1 - F^1)\, g \qquad (2)$$

During coasting $F = 0$, and if we assume the resistance to motion uniform, $(= F_c)$ we get

$$w a_3 = - F_c\, g \qquad (3)$$

Similarly during braking (with F_b as resistance),

$$w a_4 = - F_b\, g \qquad (4)$$

It is not essential to the method of the paper that straight line coasting and braking curves be assumed (*i.e.*, that F_c and F_b be assumed constant), but as this is likely to be as close to the average actual case as any other specific assumptions, and as furthermore this is not a discussion of train resistance or of braking curves, we shall make the above assumptions where we deal with coasting or braking.

V.—The Speed Curve.

The chief feature of this system is the treatment of speed-curve running, for the dynamical equations present no difficulty during the periods of accelerating, coasting and braking. In order to

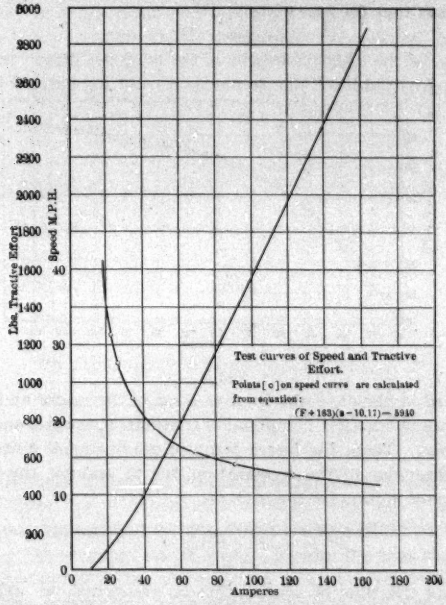

Lbs. Tractive Effort
Speed M.P.H.
Amperes
Test curves of Speed and Tractive Effort.
Points [c] on speed curve are calculated from equation:
(F + 183)(s − 10.17) = 5910

Fig. 5.

make analytical use of equation 1 during the period in question, it is necessary to construct an empirical formula connecting tractive force and speed for the working portion of the speed-curve. Now, the speed curve has all the appearance of a rectangular hyperbola, and as a matter of fact the hyperbola,

$$(F+F_0)\,(s-s_0) = K\,F_0\,s_0 \qquad (5)$$

can, by proper adjustment of the constants K F_0 and s_0, be made to lie extremely close to the speed curve over the whole useful range, from acceleration to free running. Figs. 5 and 6 show two typical speed-curves with the hyperbolas proposed to represent them, and it will be noticed that the hyperbola lies as close to the actual speed-curve—the working part being always understood—as would a speed-curve on another motor of the same type. In fact, it is as close as the test can be relied upon, and it is useless to attempt greater accuracy than this.

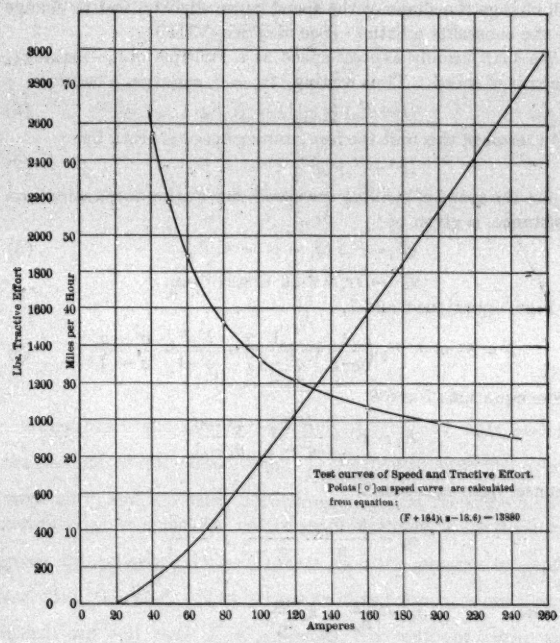

Lbs. Tractive Effort
Miles per Hour
Amperes
Test curves of Speed and Tractive Effort.
Points [o] on speed curve are calculated from equation:
(F + 184)(s − 18.6) = 13580

FIG. 6.

The curves of Figs. 5 and 6 are in no way exceptional, but represent what in the author's experience are average cases, so that the assumption that the speed-tractive-effort curve can be represented by such an equation as 5, appears fully justified. I have dwelt upon this point as it is the fundamental assumption of this method of treatment, and anyone

doubting the accuracy of the results has practically to show where the assumption fails, for the rest is purely mathematics.

Concerning the constants.—K depends only on the *shape* of the curve, and for an average well-shaped characteristic lies in the neighborhood of $3\frac{1}{2}$ or 4. F_0 is of the dimensions of force. It varies as the gear reduction ratio and inversely as the diameter of the wheels. s_0 is a speed, varying inversely as the gear reduction ratio and directly as the diameter of the wheels. It also practically varies as the voltage, though a large change in voltage will change the shape of the speed curve slightly, and so change all the constants a little. (See also Sec. VIII.)

We shall usually express speed as a multiple of s_0—making s_0 the unit of speed. Thus writing $s/s_0 = q$, equation 5 becomes

$$(F+F_0)\,(q-1) = K\,F_0 \tag{6}$$

In terms of this unit the free running speed is given by

$$(F^1+F_0)\,(q^1-1) = K\,F_0 \tag{7}$$

whilst the speed of striking the speed-curve after acceleration on resistance, is given by:

$$(F_1+F_0)\,(q_1-1) = K\,F_0 \tag{8}$$

VI.—Dynamics Continued.

From equations 6 and 7,

$$F - F^1 = K\,F_0\left(\frac{1}{q-1} - \frac{1}{q^1-1}\right) = \frac{K\,F_0}{q^1-1}\cdot\frac{q^1-q}{q-1} \tag{9}$$

From equations 7 and 8

$$F_1 - F^1 = \frac{K\,F_0}{q^1-1}\cdot\frac{q^1-q_1}{q_1-1}$$

whence, from equation 2,

$$a_1 = \frac{K\,F_0\,g}{w}\cdot\frac{1}{q^1-1}\cdot\frac{q^1-q_1}{q_1-1}$$

Now,
$$t_1 = \frac{s_1}{a_1} = s_0\,\frac{q_1}{a_1}$$

$$= \frac{w\,s_0}{K\,F_0\,g}\cdot(q^1-1)\,q_1\,\frac{q_1-1}{q^1-q_1} \tag{10}$$

The distance $d_1 = \frac{1}{2}\,s_1\,t_1 = \frac{1}{2}\,s_0\,q_1\,t_1$

$$= \frac{w\,s_0^2}{K\,F_0\,g}\cdot(q^1-1)\,\frac{q_1^2}{2}\cdot\frac{q_1-1}{q^1-q_1} \tag{11}$$

From equation 1,

$$d t = \frac{w}{g} \cdot \frac{d s}{F - F^1} = \frac{w s_0}{g} \cdot \frac{d q}{F - F^1}$$

whence, from equation 9,

$$d t = \frac{w s_0}{K F_0 g} \cdot (q^1 - 1) \frac{q - 1}{q^1 - q} d q \qquad (12)$$

$$\therefore t_2 = \frac{w s_0}{K F_0 g} (q^1 - 1) \int_{q_1}^{q_2} \frac{q - 1}{q^1 - q} d q$$

$$= \frac{w s_0}{K F_0 g} (q^1 - 1) \left[- (q - 1) - \log_e \frac{q^1 - q}{q^1 - 1} \right]_1^2 \qquad (13)$$

$$d_2 = \int s \, d t = s_0 \int q \, d t$$

$$= \frac{w s_0^2}{K F_0 g} (q^1 - 1) \int_{q_1}^{q_2} \frac{q (q - 1)}{q^1 - q} d q$$

$$= q^1 s_0 t_1 - \frac{w s_0^2}{K F_0 g} \frac{q^1 - 1}{2} \left[(q - 1)^2 \right]_1^2 \qquad (14)$$

Equations 10 and 13 give respectively the times t_1 and t_2 each as the product of two factors—one, $\frac{w s_0}{K F_0 g}$ depending on the equipment only, and the other depending on q^1 and therefore on the resistance to traction, *i.e.*, on the grade. Similarly the distances given by equations 11 and 14 are each the product of $\frac{w s_0^2}{K F_0 g}$ and a function of q^1. Now, just as we have taken s_0 as our unit of speed, we will take $T = \frac{w s_0}{K F_0 g}$ as our unit of time, and $D = \frac{w s_0^2}{K F_0 g}$ as our unit of distance, writing T and D for shortness, as these quantities occur frequently. This is an obvious piece of manipulation, but at the same time is most important. It enables all the infinite possibilities of the subject to be expressed in one system of curves, which cover all equipments and all

grades, and which, having been once computed, reduce all problems to mere reference to them. These curves are placed on record in various forms in plates I., II. and III.

With T and D as units of time and distance, equation 10 reduces to

$$t_1 = (q^1 - 1)\, q_1 \frac{q_1 - 1}{q^1 - q_1} \tag{15}$$

Equation 11, to

$$d_1 = (q^1 - 1)\, \frac{q_1^2}{2}\, \frac{q_1 - 1}{q^1 - q_1} \tag{16}$$

Equation 13, to

$$t_2 = (q^1 - 1) \left\{ \left[-(q_2 - 1) - \log_e \frac{q^1 - q_2}{q^1 - 1} \right] - \left[-(q_1 - 1) - \log_e \frac{q^1 - q_1}{q^1 - 1} \right] \right\} \tag{17}$$

Equation 14, to

$$d_2 = q^1 t_2 - \frac{q^1 - 1}{2} \left\{ (q_2 - 1)^2 - (q_1 - 1)^2 \right\} \tag{18}$$

If we adopt these same units of time and distance whilst coasting and braking, we get from equation 3

$$t_3 = \frac{K F_0}{F_c} \cdot (q_2 - q_3) \tag{19}$$

$$d_3 = \frac{K F_0}{F_c} \frac{q_2^2 - q_3^2}{2} \tag{20}$$

where q_3 is the speed at the end of coasting.

Similarly, from equation 4,

$$t_4 = \frac{K F_0}{F_b} (q_3 - q_4) \tag{21}$$

$$d_4 = \frac{K F_0}{F_b} \frac{q_3^2 - q_4^2}{2} \tag{22}$$

where q_4 is the speed after braking, which of course equals zero if the train is stopped.

For the usual stop, coasting followed by braking, we get for the total time with power off,

$$t_3+t_4 = \frac{K F_0}{F_c} q_2 - \left(\frac{K F_0}{F_c} - \frac{K F_0}{F_b}\right) q_3 \qquad (23)$$

and for the total distance,

$$d_3+d_4 = \frac{K F_0}{F_c} \frac{q_2^2}{2} - \left(\frac{K F_0}{F_c} - \frac{K F_0}{F_b}\right) \frac{q_3^2}{2} \qquad (24)$$

whilst, if there is no coasting, $q_2 = q_3$.

The kinematics of the subject, as treated by this method, is entirely included in equations 15 to 24.

VII.—Universal Speed Time and Distance Curves.

Plate I. gives curves between q and t, where

$$t = (q^1 - 1)\left\{ - (q-1) - \log_e \frac{q^1 - q}{q^1 - 1} \right\} \qquad \text{(see equation 17)}$$

for different values of q^1, that is, with a particular equipment, of train resistance; (the figures attached to the several curves are the values of q^1 for which they are plotted.) These are universal speed-time curves corresponding to that portion of the run which is made on the speed-curve. The time spent on the speed-curve is the difference between the ordinates at q_2 and q_1 of the particular curve for which the constant q^1 corresponds to the equipment and resistance in question. If, having reached the speed q_2, we strike another grade, we simply determine the value of q^1 for this grade, and stepping to the corresponding curve at the same abscissa q_2, proceed the requisite time on this latter curve, and so on.

Curves corresponding to the lower free-running speeds have a second branch in which the speed approaches free-running from above. These are for use when we happen to strike a grade at a speed higher than the free-running speed corresponding to that grade, and require no special treatment.

Plate II. gives universal speed-distance curves, from the equation,

$$d = q^1 t - \frac{q^1 - 1}{2} (q-1)^2 \qquad \text{(see equation 18)}$$

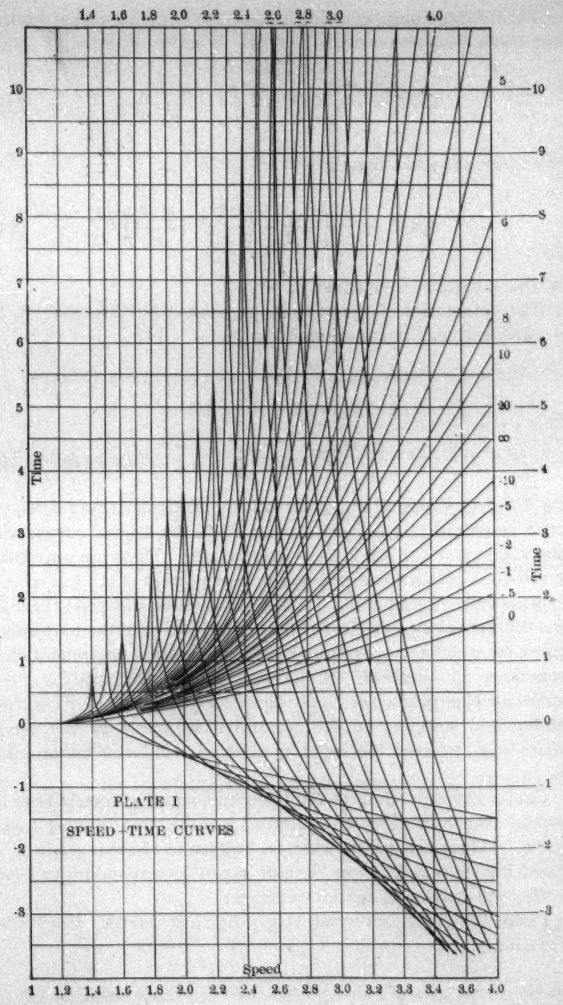
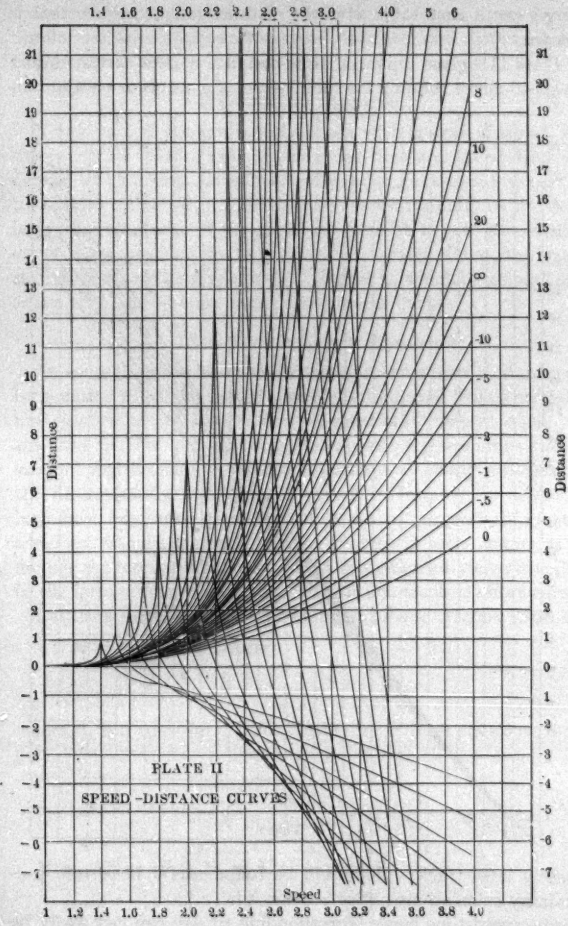


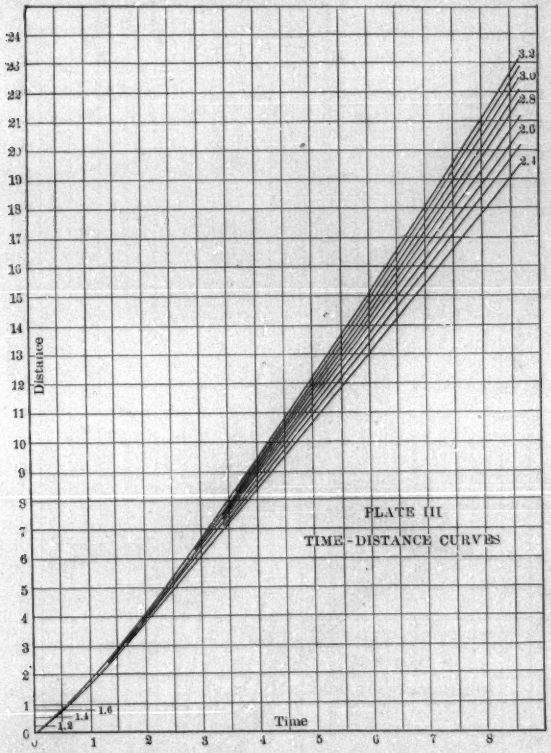
PLATE I

SPEED–TIME CURVES


1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 4.0 5 6
8
10
20
∞
-10
-5
-2
-1
-.5
0
Distance
Distance
PLATE II
SPEED -DISTANCE CURVES
Speed
1 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0

These are used in the same manner as the speed-time curves, and are perhaps more generally useful, since in such work as laying out a time table, it is the distance on each grade that is known.

Plate III. gives universal time-distance curves corresponding to speed-curve running for such values of q^1 as occur on approxi-



mately level track. They will be found useful in certain preliminary calculations. [See Section XIV. c.]

The speed-time curve corresponding to any run can easily be plotted. The portions of it which represent acceleration, coasting, and braking are straight lines, and present no difficulty,

whilst the portion representing speed-curve running is copied directly from the appropriate curve in Plate I.—the time coördinate being multiplied by T and the speed coördinate by s_0. Similar remarks apply to the speed-distance, and distance-time curves. [See Section XIV. e.]

VIII.—Series Running.

If any part of the run is to be made with motors in series, we can negotiate it by means of our speed-time and speed-distance curves, by changing the scale of ordinate and abscissa, practically by halving s_0, better, if there is much series running, by recalculating the constants of the speed-curve so as to give the correct curve corresponding to half potential. From these new constants we obtain new values of T, D and s_0, which determine the scales in the speed-time and speed-distance curves.

IX.—The Current Equation.

An inspection of the curve between tractive force and current for a motor will show that it is never far removed from a straight line—remembering always that we need only concern ourselves with the portion between accelerating and free-running—and a straight line judiciously chosen is perhaps as nearly accurate as the nature of the subject will permit. However, it does not introduce any very great complication to proceed to greater accuracy, and we shall perform the analysis in such manner as to include the more general case, whilst being immediately reducible to the form corresponding to a straight line tractive effort curve.

Let the straight line between current (I.) and tractive force be,

$$I = \frac{I_0}{K F_0}(F + F_i) \tag{25}$$

where F_i is a constant. Substituting for F from equation, 6 we get,

$$I = \frac{I_0}{K F_0}\left\{\frac{K F_0}{q-1} - F_0 + F_i\right\}$$

Now writing, $F_i - F_0 = K F_0 b$, we get

$$I = I_0\left\{\frac{1}{q-1} + b\right\} \tag{26}$$

This is a hyperbola connecting current and speed, which assumes a straight line law connecting current and tractive force. If now we put,

$$I = I_0 \left\{ \frac{1}{q - q_i} + b \right\} \tag{27}$$

we can adjust the three constants I_0 q_i and b, so as to make the hyperbola of equation 27 cross the speed-current curve at three points within the useful range, and practically coincide with it. By putting $q_i = 1$ in any result deduced from equation 27 we reduce it to the corresponding result for equation 26.

The free running current is,

$$I^1 = I_0 \left(\frac{1}{q^1 - q_i} + b \right) \tag{28}$$

and the accelerating current,

$$I_1 = I_0 \left(\frac{1}{q_1 - q_i} + b \right) \tag{29}$$

The ampere-time curve, for that portion of the run which is made on the speed-curve, can be deduced from the speed-time curve and equation 26 or 27. [See Section XIV. e.]

X.—Energy Required.

Assuming series-parallel control, the energy taken per motor during acceleration in series, is,

$$\tfrac{1}{2} V \times \tfrac{1}{2} t_1 T I_1$$

during acceleration in multiple twice this amount is used, so that the total energy required during acceleration is,

$$E_1 = \tfrac{3}{4} V I_1 t_1 T \text{ watt-seconds} \tag{30}$$

The energy required during speed curve running is,

$$E_2 = V \int I \, d t$$

$$= V T \int_{q_1}^{q_2} I_0 \left(\frac{1}{q - q_i} + b \right) (q^1 - 1) \frac{q - 1}{q^1 - q} \, d q \quad \text{(See equation 12)}$$

$$= V T \left\{ I^1 t_2 + I_0 \frac{q^1 - 1}{q^1 - q_i} (q_2 - q_1) + I_0 \frac{(q^1 - 1)(q_i - 1)}{q^1 - q_i} \log_e \frac{q_2 - q_i}{q_1 - q_i} \right\} \tag{31}$$

When $q_i = 1$

$$E_2 = V T \left\{ I^1 t_2 + I_0 (q_2 - q_1) \right\} \tag{32}$$

For an extended run on several grades, the quantity within the brackets becomes,—"the sum of the value of $I^1 t_2$ for the several grades, $+I_0$ times the total increase of speed between striking the speed curve and cutting off power"—intermediate speeds on the grades cancelling. With a little trouble equation 31 can be reduced to a form almost as simple for calculation. [See Section XII., Equation 38.]

XI.—Copper Losses.

If R be the resistance of the motor (or of armature or field), the $I^2 R$ loss in this resistance is, during acceleration,

$$C_1 = R\, I_1^2\, t_1\, T \text{ watt-seconds} \qquad (33)$$

During speed-curve running,

$$C_2 = R \int I^2\, d\,t$$

$$= R\,T \int_{q_1}^{q_2} I_0^2 \left(\frac{1}{q - q_i} + b\right)^2 (q^1 - 1)\, \frac{q-1}{q^1 - q}\, d\,q$$

$$= R\,T \left\{ I^2\, t_2 + I_0\,(I^1 + b\, I_0)\, \frac{q^1 - 1}{q^1 - q_i}\, (q_2 - q_1) \right.$$

$$+ I_0^2 \left[\frac{(q^1 - 1)^2}{(q^1 - q_i)^2} + 2\, b\, \frac{(q_i - 1)\,(q^1 - 1)}{q^1 - q_i} \right] \log_e \frac{q_2 - q}{q_1 - q_i}$$

$$\left. + I_0^2\, \frac{(q_i - 1)\,(q^1 - 1)}{q^1 - q_i} \left(\frac{1}{q_1 - q_i} - \frac{1}{q_2 - q_i} \right) \right\} \qquad (34)$$

If we put $q_i = 1$, this reduces to

$$C_2 = R\,T \left\{ I^2\, t_2 + I_0\,(I^1 + b\, I_0)\,(q_2 - q_1) + I_0^2 \log_e \frac{q_2 - 1}{q_1 - 1} \right\} \qquad (35)$$

For a run in which power is kept on over a number of different grades the terms $I^2\, t_2$ and $I_0\, I^1\,(q_2 - q_1)$ have to be computed for each grade, whilst in the other terms intermediate speeds cut out and the sum depends only on the speed of striking and leaving the speed-curve. Although it is not usual to compute the losses for such extended runs, it is nevertheless advisable to place the method of calculation on record.

XII.—Iron Losses.

The core loss of a motor cannot be calculated with any accuracy, but when it has been determined by test, we can compute the iron losses corresponding to any run, although of course the reliability of the result is not greater than that of the core loss, so that it is useless to aspire to too great accuracy.

During acceleration on resistance the mean core loss is rather less than a half of the maximum and may with sufficient accuracy be taken as $0.4\,W_1$ where W_1 is the core loss on reaching the motor curve at the accelerating current. Thus we may write,

$$L_1 = .4\,W_1\,t_1\,T \tag{36}$$

The core loss at constant voltage has usually to be drawn through a very few test points, and if we can find an empirical formula which represents a smooth continuous curve through these test points—at any rate such of them as lie within the useful range—this formula will represent the core loss quite as well as the usual arbitrary curve through the points. Whilst I am not prepared to propose a formula that will suit all core loss curves, I have found that the commonest shape—that which rises continually with the current, if plotted against speed, can be closely represented by a hyperbola of the form,

$$(W - W_0)\,(q - q_0) = P \tag{37}$$

where the constants P, w_0 and q_0 are chosen to make the curve pass through three test points within the useful range.

The iron loss during speed-curve running is obtained from equation 37 by the same integration as the energy is obtained in equation 31. Thus,

$$L_2 = \int W\,d\,t$$

$$= T\left\{W^1 t_2 + P\frac{q^1 - 1}{q^1 - q_0}(q_2 - q_1) - P\frac{(1-q_0)\,(q^1-1)}{q^1 - q_0}\log_e\frac{q_2 - q_0}{q_1 - q_0}\right\}$$

$$= T\left\{W^1 t_2 - P\frac{1 - q_0}{q^1 - q_0}\cdot(q_2 - q_1) + P\frac{(1-q_0)^2}{q^1 - q_0}\log_e\frac{q_2 - q_0}{q_1 - q_0}\right.$$

$$\left. + P\,(q_2 - q_1) - (1 - q_0)\log_e\frac{q_2 - q_0}{q_1 - q_0}\right\} \tag{38}$$

The last form of the above equation is for use on a run over several grades. In it the first term is the important one, the second and third are small, whilst the last two depend only on the speeds of reaching and leaving the motor curve.

XIII.—Remarks.

The foregoing sections provide us with all the tools required in the subject, in the form of a score or so of equations and a few systems of curves. The equations, being in general form, are independent of any particular system of units. In the examples that follow, intended merely to show the use and application of the method—we shall adopt the units usual in this country—miles per hour, watt hours per ton mile, etc.

XIV.—Examples.

(*a*) Equation of speed-tractive-effort curve:

In order to determine the constants K, F_0 and s_0 of equation 5, we select three points on the motor curve—one near free running, one near accelerating, and the third about half-way between these two—and compute the values of the above constants, which will make the hyperbola pass through these points. Thus from Fig. 5 we get,

Speed (m.p.h.)	Tractive Effort (lbs.)
27.5	180
19.0	510
14.1	1350

Now, equation 5 may be written,

$$F s + F_0 s - F s_0 = (K+1) F_0 s_0 \qquad (39)$$

Thus,

$$27.5 \times 180 + 27.5 F_0 - 180 s_0 =$$

$$19.0 \times 510 + 19.0 F_0 - 510 s_0 =$$

$$14.1 \times 1350 + 14.1 F_0 - 1350 s_0 = (K+1) F_0 s_0$$

or

$$4950 + 27.5 F_0 - 180 s_0 =$$

$$9690 + 19 F_0 - 510 s_0 =$$

$$19035 + 14.1 F_0 - 1350 s_0 = (K+1) F_0 s_0 \qquad (40)$$

$$\therefore 4740 = 8.5 F_0 + 330 s_0 \qquad (41)$$

$$9345 = 4.9 F_0 + 840 s_0 \qquad (42)$$

Multiplying equation 41 by $4.9/8.5$, we get,

$$2735 = 4.9 F_0 + 190 s_0$$

subtracting this from 42 gives

$$6610 = 650\, s_0$$

$$\therefore s_0 = 10.17 \text{ m.p.h.} = 14.92 \text{ f.p.s.}$$

From equation 41 we get,

$$8.5\, F_0 = 4740 - 3356 = 1384$$

$$\therefore F_0 = 163 \text{ lbs.}$$

whence from equation 40,

$$(K+1) \times 1658 = 4950 + 4480 - 1830 = 7600$$

or

$$K = 3.585$$

Thus, the equation of the speed curve is

$$(F + 163)\,(s - 10.17) = 3.585 \times 10.17 \times 163$$

$$= 5940 \qquad (43)$$

This gives the constants for this motor, running at 500 volts with gear reduction ratio 4.31. Fig. 5 shows some points calculated from the above equation.

(*b*) Equation of current curve:

If we wish to determine the current accurately, as given by equation 27, the problem is the same as the last. We select three speeds, and read the corresponding currents from the test curve, then proceed to find the constants of equation 27 just as we did those of equation 5 in the last problem. Thus, from the curve of Fig. 5 we get:

$$I = 40.6 \left\{ \frac{1}{q - .918} + .081 \right\} \qquad (44)$$

If the less exact form of equation 26 is sufficient, we select two points and read current and tractive effort, then determine the equation of the straight line joining the points. Thus, from Fig. 5 we get,

Amperes.	Tractive-effort (lbs.)
34	300
80	1155

whilst

$$K F_0 = 584$$

Hence, from equation 25, we get,

$$584 \times 34 = I_0 (300 + F_i)$$

$$584 \times 80 = I_0 (1155 + F_i)$$

$$\therefore \quad 584 \times 46 = 855\, I_0$$

$$\therefore \quad I_0 = 31.4$$

$$F_i = 332$$

giving,

$$b = (332 - 163)/584$$

$$= .29$$

Thus,

$$I = 31.4 \left\{ \frac{1}{q - 1} + .29 \right\} \qquad (45)$$

The current equation in this form (or that of equation 44), is independent of gear reduction ratio and practically of the voltage.

(*c*) To determine the characteristics of a motor equipment required to handle a given service:

Let it be required to make a schedule speed of 17 m.p.h., allowing two stops per mile of 10 seconds each, and assuming that 10 per cent. of the total time will be consumed in unavoidable delays. Let the estimated effective weight of the train be eight tons per motor, and the friction 20 lbs. per ton of effective weight, or 160 lbs. per motor in all. Let acceleration and braking retardation be both at the rate of 1.32 m.p.h. per sec., requiring 120 lbs. per ton, so that the total force required per motor during acceleration is $8 \times 140 = 1120$ lbs. Let us allow moreover for 10 per cent. of the distance being coasted. Thus we must calculate on making 17 miles in 54 minutes, and the typical run is one of one-half mile in 95.3 seconds, including a stop, or of 2640 feet in 85.3 seconds actual running time.

We first make a calculation of the distance and time power is off—estimating the maximum speed reached, say 31 m.p.h in this case. Then,

Coasting distance, 264 feet. Coasting time, 5.9 seconds.
Speed at end of coasting, 29.7 m.p.h.
Braking distance, 490 feet. Braking time, 22.5 seconds.
Distance power off, 754 feet. Time power off, 28.4 seconds.
Distance power on, 1886 feet. Time power on, 56.9 seconds.

Assume for the speed curve,

$$(F+F_0)(q-1) = 4F_0$$

which is about an average shape; also assume that free running on the level is reached when $q = 2.5$, (this is about the usual thing in street railway work), then,

$$(160+F_0)(2.5-1) = 4F_0 \qquad \text{(See equation 7)}$$

$$\therefore F_0 = 96 \text{ lbs.}$$

$$T = \frac{16000}{4 \times 96 \times 32.2} s_0 = 1.3 s_0$$

$$D = 1.3 s_0^2$$

Thus, if t and d are respectively the total time and distance that power is on, expressed in terms of our usual units:

$$1.3 s_0 t = 56.9 \text{ seconds.}$$

$$1.3 s_0^2 d = 1886 \text{ feet}$$

$$\therefore \frac{\sqrt{d}}{t} = \frac{\sqrt{1886 \times 1.3}}{56.9} = .87$$

Now, the speed of striking the speed curve is given by,

$$(1120+96)(q_1-1) = 384 \qquad \text{(See equation 8)}$$

$$\therefore q_1 = 1.316$$

$$t_1 = .525 \qquad \text{(See equation 15)}$$

$$d_1 = .35 \qquad \text{(See equation 16)}$$

Referring to Plate III (or Plates I and II), we see that the reading on the curve, "2.5" corresponding to speed 1.316 is—time .065 distance, .06. Now, if τ be the reading of time, and δ that of distance, when the power is cut off,

$$t = \tau + .525 - .065 = \tau + .46$$

$$d = \delta + .35 - .06 = \delta + .29$$

Thus, we have to determine the point on curve "2.5," Plate III., which satisfies,

$$\frac{\sqrt{\delta + .29}}{\tau + .46} = .87$$

This we find by trial to be,

$$\tau = 1.68$$

$$\delta = 3.18$$

Hence $$s_0 = \frac{56.9}{1.3(1.68+.46)} = 20.5 \text{ f.p.s.} = 13.95 \text{ m.p.h.}$$

The reading of speed at time 1.68 on curve "2.5," plate I., is 2.18, which makes the speed just before cutting off power,

$2.18 \times 13.95 = 30.4$ m.p.h. For the purpose of a preliminary calculation this will probably be sufficiently near to the 31 m.p.h. assumed.

Thus we have found the constants of the speed-tractive-effort curve suitable for this service. Fig. 7 shows the curve so determined.

The curves of Plate III. can be used in a very similar manner to determine the gear reduction required with a given motor in order to handle a given service.

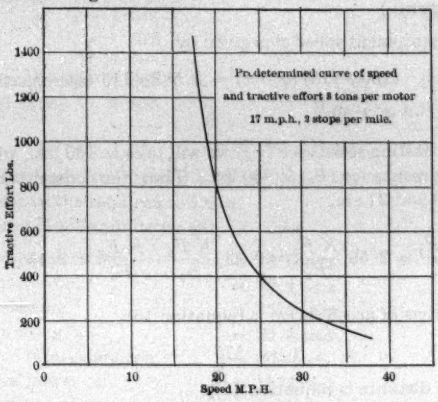


FIG. 7.

(*d*) Given the train and equipment, to determine how to make the schedule.

Let the train and schedule be the same as in the last example (*c*), and the motor that whose characteristic is given in Fig. 5 (see example *a*), but with gear reduction 3.05

Then from equation 43 we get,

$$F_0 = \frac{3.05}{4.31} \times 163 = 115 \text{ lbs.}$$

$$s_0 = \frac{4.31}{3.05} \times 10.17 = 14.4 \text{ m.p.h.} = 21.1 \text{ f.p.s.}$$

$$K = 3.585$$

$$w = 16000$$

$$T = \frac{16000 \times 21.1}{3.585 \times 115 \times 32.2} = 25.45 \text{ seconds.}$$

$$D = 25.45 \times 21.1 = 537 \text{ feet.}$$

As in the last example, we have to make 2640 feet in 85.3 seconds, or in our units, distance 4.92 in time 3.355. Let acceleration and braking be as in the last example; thus the speed q_1 of striking the speed curve is given by

$$(1120+115)\,(q_1-1) = 3.585\times 115 \text{ (see equation 8)}$$

or $$q_1 = 1.335$$

(Equation 44 shows this corresponds to acceleration at about 100 amperes.)

The equipment speed q^1 is given by,

$$(160+115)\,(q^1-1) = 3.585\times 115 \text{ (see equation 7)}$$

or $$q^1 = 2.50$$

The coasting resistance (F_c) we will take as 160 lbs., whilst the braking resistance (F_b) is 960 lbs. Thus, the constants of equations 23 and 24 are,

$$\frac{K F_0}{F_c} = 2.58, \frac{K F_0}{F_b} = 0.43, \frac{K F_0}{F_c} - \frac{K F_0}{F_b} = 2.15$$

The time of acceleration is (equation 15),

$$t_1 = .575$$

and the distance is (equation 16),

$$d_1 = .38$$

We now proceed to determine the instant when we must cut off power in order to make the given distance in the given time. Thus try $q_2 = 2.2$, whence from Plate I.,

$t_2 = 1.81 - .06 =$	1.75
$t_1 =$	.575
Time power on,	2.325
Total time,	3.355
$\therefore$ Time power off,	1.03

whence (equation 23),

$$2.15\,q_3 = 2.58\times 2.2 - 1.03 = 4.645$$

$$q_3 = 2.16$$

Thence from equation 18 (or Plate II.),

$$\begin{aligned} d_3 &= 3.38 \\ d_1 &= .38 \\ d_3+d_4 &= 1.23 \qquad \text{(see equation 24)} \\ \text{Total distance,} &\quad 4.99, \text{ instead of } 4.92 \end{aligned}$$

Thus we make somewhat too great a distance in the time, and must cut off power earlier. Taking $q_2 = 2.13$, we get,

$$\begin{aligned} t_2 &= 1.37 & q_3 &= 1.90 \\ t_1 &= .575 & d_2 &= 2.55 \\ t_1+t_2 &= 1.945 & d_1 &= .38 \\ \text{Total time,} &\quad 3.355 & d_3+d_4 &= 1.98 \\ t_3+t_4 &= 1.41 & \text{Total distance,} &= 4.91 \end{aligned}$$

This then leads to, distance 4.91 in time 3.355, which is sufficiently near to the required solution.

Resuming familiar units we get,

Time of acceleration,	= 14.6 secs.
Time power on,	= 49.4 secs.
Time coasting,	= 15.1 secs.
Time braking,	= 20.8 secs.
Distance of acceleration,	= 206 feet.
Distance power on,	= 1573 feet.
Distance coasting,	= 648 feet.
Distance braking,	= 416 feet.
Speed on striking motor curve,	= 19.2 m.p.h.
Speed on cutting off power,	= 30.65 m.p.h.
Speed on beginning to brake,	= 27.35 m.p.h.

(*e*) To plot speed-time and current-time curves.

Having determined the duration of the several parts of the run as in the last problem, we can immediately put in the portions of the speed-time curve corresponding to accelerating, coasting and braking—which consist of straight lines. The portion that is run on the motor curve is copied from the appropriate curve ($q^1 = 2.5$) in Plate I, the speed coördinate being multiplied by $s_0 = 14.4$ m.p.h., and the time coördinate by $T = 25.45$ seconds. If we add to the reading of time in plate I. the time of acceleration (.575) and subtract the reading (.06) on first striking the speed curve, we shall arrive at the time measured from the beginning of the run.

Thus, for $q = 2.0$, we get for the reading of time, .97, whence the time from the beginning of the run is $.97 + .515 = 1.485$ or 37.8 secs., and the speed is $2.0 \times 14.4 = 28.8$ m.p.h. The current per motor is given by equation 44 or 45, according to the accuracy desired.

These curves are plotted in Fig. 8, which shows also some points calculated by the usual point-to-point method, from the curve in Fig. 5.

Speed distance curves can be plotted in a similar manner from equations 16, 20 and 22 and Plate II.

(*f*) Energy used.

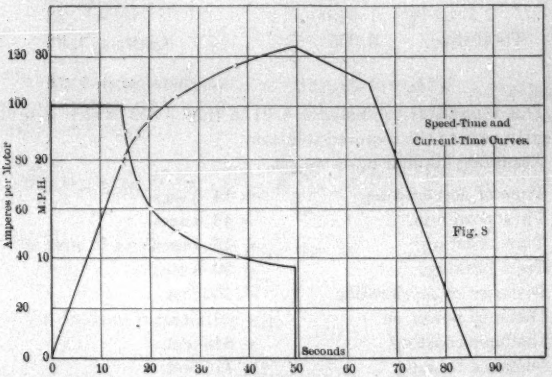


Fig. 8.

Equation 44 with equations 28 and 29, gives:

$$I^1 = 29 \text{ amps.}$$
$$I_1 = 100.7 \text{ amps.}$$

Hence, from equation 30,

$$E_1 = \tfrac{3}{4} \times 500 \times 100.7 \times .575 \times 25.45$$
$$= 552000 \text{ watt-seconds}$$

From equation 31,

$$E_2 = 500 \times 25.45 \left\{ 29 \times 1.37 + 40.6 \frac{1.5}{1.582} \times .795 \right.$$
$$\left. - 40.6 \frac{1.5}{1.582} \times .082 \times 2.3 \times .463 \right\}$$
$$= 500 \times 25.45 \{ 39.8 + 30.6 - 3.4 \}$$
$$= 852000 \text{ watt-seconds}$$

Total energy input = 1404000 watt-seconds

Which gives 97.5 watt-hours per ton mile.

Equations 45, 30 and 31 lead to,

$$E_1 = 564000 \text{ watt-seconds}$$
$$E_2 = 845000 \text{ watt-seconds}$$

In all 1409000 watt-seconds, differing from the more exact calculation given above, by only 0.35% in this case.

(g) Motor losses:

Calculating copper losses from the less exact current equation (No. 45), we get, from equation 33,

$$C_1 = R \times 103^2 \times .575 \times 25.45$$
$$= R \times 155000 \text{ watt-seconds}$$

whilst from equation 35 we get,

$$C_2 = R \times 25.45 \{1236 + 975 + 1200\}$$
$$= R \times 86800 \text{ watt-seconds.}$$

Total copper loss = $R \times 242000$ watt-seconds.

The more exact calculation, using equations 44 and 34, gives the total copper loss as $R \times 237000$ watt-seconds.

Now, the hot resistances are,

Armature, .108 ohms
Field, .214 ohms

Thus, the total copper losses are,

Armature, 25600 watt-seconds.
Field, 50700 watt-seconds.

These losses correspond to $\frac{1}{2}$ mile or 1/34 of an hour, thus the mean losses during the time of running are,

Armature, 242 watts.
Field, 478 watts.

The core loss on this machine is closely represented by,

$(W - 940)(q - .705) = 456$ (See equation 37.)

Thus,

$$W_1 = 940 + \frac{456}{.63} = 1665 \text{ watts}$$

$$W^1 = 940 + \frac{456}{1.795} = 1195 \text{ watts}$$

Hence, from equation 36,

$$L_1 = .4 \times 1665 \times .575 \times 25.45$$
$$= 9730 \text{ watt-seconds}$$

From equation 38,

$$L_2 = 25.45 \{1638 + 303 - 91\}$$
$$= 47100 \text{ watt-seconds}$$

Hence, the total core loss during the run is 56830 watt-seconds, and the mean loss is 537 watts.

(*h*) Calculation of time between stops, taking account of grades, curves, etc.; also determination of energy input.

As a final example take the case of a train having actual weight per motor car of 52½ tons, and effective weight, 58 tons, each car being equipped with four motors of the type whose speed curve is given in Fig. 6. Thus, $F_0 = 184$ lbs., $K = 4.06$, $s_0 = 18.6$ m.p.h. $= 27.25$ f.p.s.

The grades in a long run between two stops are given in Table I., with the results of the calculations. The first 500 feet is run in series as the speed is limited to 10 m.p.h. over the following 400 feet, on account of crossings; afterwards, the run is made in full multiple.

The current curve is approximately,

$$I = 58 \left(\frac{1}{q-1} + .39 \right)$$

Acceleration is taken at 190 amperes per motor, braking at 120 lbs. and train resistance at 15 lbs. per effective ton.

Thus,

$$w = 29000 \text{ lbs.}$$

$$T = \frac{29000 \times 27.25}{4.06 \times 184 \times 32.2} = 32.95 \text{ seconds}$$

$$D = 32.95 \times 27.25 = 897 \text{ feet}$$

$$\text{Friction} = 217.5 \text{ lbs.}$$

q_1 is given by

$$\frac{1}{q_1 - 1} = \frac{190}{58} - .39, \text{ or } q_1 = 1.346 \qquad \text{(equation 29)}$$

Also,

$$\frac{KF}{F_b} = .43 \qquad \text{(equations 21 and 22}$$

In the accompanying table, the first column gives the grade; the second gives the distance on that grade, in feet; the third this distance divided by 897, *i.e.*, reduced to our usual units; the fourth, the resistance per motor on the particular grade, being $217.5+262.5\times\%$ grade, whilst the fifth gives the free running speed corresponding to the grade, from equation 7, with the above constants. The sixth and seventh columns give respectively the speeds of striking and leaving the speed curve on the particular grade. The eighth column gives the distance accelerating on resistance; the ninth, the distance run on the motor curve, the tenth the distance coasted, and the eleventh the distance passed over in braking. The twelfth, thirteenth, fourteenth and fifteenth columns give respectively the times corresponding to the distances in the eighth, ninth, tenth and eleventh columns. The sixteenth column gives the free running current from equation 28, with the above constants; the seventeenth is $E_1 \div V\,T$, from equation 30, whilst the eighteenth column is $E_2 \div V\,T$, from equation 32, being, after the second line, simply the value of $I^1\,t_2$, supplemented by an additional term at the end, in accordance with the remark following equation 32. The figures in brackets in the first line are in units appropriate to series running [see Sec. VIII.], whilst the second line gives the same quantities in terms of the units used in the remainder of the table, for convenience of addition.

In making the calculations we can conveniently start by setting down or determining the first five columns, after which we develop the table line by line. Thus, in the fourth line we determine t_1 and d_1, by obvious modifications of equations 15 and 16, allowing for power being applied when the speed is 0.54. Thus, we arrive at $d_1 = .29$, $q_1 = 1.345$. Subtracting .29 from the total distance 1.505, we get 1.215. Adding this to the reading (.07) of distance at $q = 1.345$ on curve 4.42, Plate II., we get 1.285, which on this curve corresponds to speed $q_2 = 2.07$, whence t_2 from equation 18. Passing now to curve 2.435 at $q = 2.07$, we get distance reading 2.26, to which to add 3.345, the distance on this grade, giving 5.605, corresponding to speed reading $q_2 = 2.285$, whence t_2 from equation 18, and so on to the end of the table. The braking point in the last line has to be determined by trial so as to bring the train to rest at the required place. The columns of time, distance and energy are summed and converted into familiar units. The speed of striking or leaving a grade can be got by multiplying q_1 or q_2 by 18.6, m.p.h.

TABLE (Sec. XIV h.)

% Grade.	Dist. Feet.	Dist.	F'	q	q_1	q_2	d_1	d_2	d_3	d_4	t_1	t_2	t_3	t_4	l'	E_1	E_2
—.70	500	[2.23]	34	4.42	[1.345]	[2.07]	[.35]	[1.21]	—	[.67]	[.515]	[.67]	—	[.43]			
"	"	.555	"		.67	1.035	.09	.30	—	.17	.26	.335	—	.215	39.6	24.5	17.1
"	400	.445	"	"	(Speed 10 m.p.h.		- .54)		.445	—	—	—	.825	—	—	—	—
"	1350	1.505	"	"	1.345	2.07	.29	1.215	—	—	.31	.67	—	—	"	54.2	26.5
+.45	3000	3.345	336	2.435	2.07	2.285	—	3.345	—	—	—	1.525	—	—	63.0	—	96.1
—.50	2300	2.565	86	3.76	2.285	2.615	—	2.565	—	—	—	1.035	—	—	43.6	—	45.1
+.16	7900	8.81	260	2.68	2.615	2.66	—	8.81	—	—	—	3.335	—	—	57.1	—	190.0
+.60	2300	2.565	375	2.335	2.66	2.545	—	2.565	—	—	—	.995	—	—	66.1	—	65.7
+.09	3400	3.79	241	2.755	2.545	2.635	—	3.79	—	—	—	1.47	—	—	55.7	—	81.8
+.65	5300	5.91	388	2.305	2.635	2.415	—	5.91	—	—	—	2.375	—	—	67.0	—	159.1
—.48	1900	2.12	92	3.70	2.415	2.65	—	2.12	—	—	—	.835	—	—	44.1	—	36.8
+.48	1300	1.45	344	2.415	2.65	2.60	—	1.45	—	—	—	.555	—	—	63.6	—	35.3
—.18	1900	2.12	170	3.11	2.60	2.70	—	2.12	—	—	—	.795	—	—	50.1	—	39.8
L	2500	2.79	217	2.86	2.70	2.74	—	2.79	—	—	—	1.02	—	—	53.8	—	54.8
+.21	2000	2.23	273	2.63	2.74	2.715	—	2.23	—	—	—	.82	—	—	58.2	—	47.7
+.66	1200	1.34	391	2.30	2.715	2.63	—	1.34	—	—	—	.50	—	—	67.3	—	33.6
—.65	1400	1.56	47	4.23	2.63	2.79	—	1.56	—	—	—	.58	—	—	40.6	—	23.6
+.75	1700	1.895	414	2.25	2.79	2.625	—	1.895	—	—	—	.685	—	—	69.0	—	47.2
+.11	1200	1.34	246	2.735	2.625	2.64	—	1.34	—	—	—	.505	—	—	56.1	—	28.4
+.50	1900	2.12	349	2.40	2.64	2.615	—	.65	—	1.47	—	.245	—	1.125	64.1	—	15.7
																	73.6
	43450	feet.									Total time		- 21.0	- 692 secs.			1197
																	- 6.3 K.W. Hours.

whilst at any intermediate point the corresponding value of q is got from Plate II., so that complete curves of speed-time or speed-distance could easily be plotted. Variable friction might be taken account of by dividing the variation into definite steps and treating the several steps just as different grades are treated.

XV.—Conclusion.

The method developed above is flexible enough to take account of all the vital circumstances of a problem, whilst it is free from the possible cumulative errors of a point-to-point method, and introduces no inaccuracy in any way comparable with that due to the uncertainty of conditions. The test curves form the basis of this, just as much as of the more obvious methods, the constants pertaining to any equipment being derived directly from these curves. We may note that the result of a calculation for an extended run, such as is given at the end of the last section, may be more accurate than the speed-time and speed-distance curves employed in deriving it. A little consideration will show that an error of interpolation on one grade will affect the time on succeeding grades in just the opposite manner to that on the grade where the error is made, and the total error from this cause is exceedingly small.

In such examples as are worked out in the last section, it is in no wise a complication to introduce actual conditions so far as they are known. In many average cases, however, actual conditions may not be determinable with any degree of accuracy, or the importance of the results may not be such as to warrant the labor of minute calculation, if it can be dispensed with. If it were not that the paper is already unduly long, we might develop a system of simple working curves, based on average conditions, which would be sufficiently accurate for the purpose in view, though they must necessarily make some sacrifices in the interests of facility.

In conclusion, I wish to express my indebtedness to the General Electric Company for its permission to make use of the curves of some of its motors in the examples worked out to illustrate the method of the paper.

Appendix.

On Variable Train Resistance.

So long as speeds are low, the variation in train resistance with change of speed is hardly worth considering, especially as the value of this resistance is not usually known with any degree of accuracy. But as the speed increases the variation of resistance

with speed becomes considerable, and must be taken into account. As indicated in Sec. XIV. (*h*) we can do this by dividing the variation into suitable steps, over each of which we assume a constant mean resistance, and treat the several steps as we should so many different grades. This is probably the easiest way of treating a single isolated problem. But where we have a good deal of work to do on a particular train and equipment, the better plan is to combine the train resistance, or the variable portion of it, with the motor curve, and so derive a fictitious

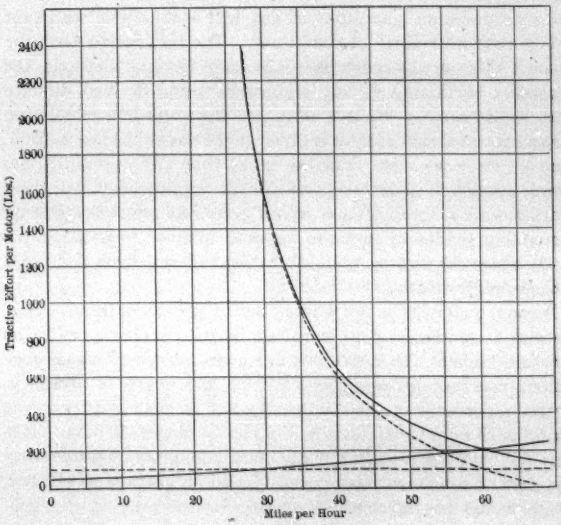


FIG. 9.

motor curve, with which we use a fictitious constant train resistance. These fictitious curves will lead to the same results as the actual motor curve and actual variable train resistance.

Fig. 9 shows, in full lines, a motor curve and resistance per motor for a particular equipment, whilst in broken lines is shown a derived fictitious motor curve, to be used with the constant train resistance also shown. The effect of grade can be added to this, just as if it were the real friction, since the resistance due to grade is independent of speed.

[Discussion on Paper of F. W. Carter.]

Mr. C. O. Mailloux:—This paper is not so abstruse as it looks. The equations appear somewhat formidable and imposing but in reality they present no great difficulty. The method is assumed to be an analytical method but there are some statements, on the first page, in reference to the "graphical" or the point-to-point method of construction, which make it desirable that I should begin the discussion by considering the point-to-point method. At the last annual meeting I read a paper entitled, "Some Notes on the Plotting of Speed-Time Curves," in which I described a graphical point-to-point method. I had intended to present, this year, at this meeting, another paper, giving an analytical method, which was hinted at in the discussion at Great Barrington (see A.I.E.E. Transactions, Vol. XIX., p. 1018), but lack of time prevented me from doing so.

I want to say something in support of the point-to-point method presented in my paper. It is a method which involves no assumptions except that the rate of retardation is assumed constant in braking. We still have to make that assumption because we have no very definite knowledge as to the nature of the braking curve; but with that exception the method is independent of any assumptions. All the data necessary for use with this method can be obtained from motor tests and from experiments; and once the fundamental curves, which I showed on the "chart of coefficients," (Fig. 9 of my paper) have been plotted, it is possible to plot the speed-time curves for any set of conditions whatever, with any desired degree of accuracy, and with little difficulty.

Mr. Carter's method, as presented, cannot presume to be more than a method of approximation, and consequently it does not altogether supplant or replace the methods described in my paper.

Singularly enough the author, himself, comes rather close, in some details, to my method for his Fig. 9, on the last page of the paper, is substantially identical with Fig. 9 of my paper: The solid line curve in Fig. 9, is one which gives gross tractive efforts as a function of the speed. The author uses the ordinates for tractive efforts per motor, in pounds. The abscissæ indicate speeds. In my paper, I also use abscissæ for speeds, and I use the same ordinate *values*, but they are plotted according to a different *scale*. I call them acceleration-coefficients (see curve *M*, Fig. 9, in A.I.E.E. Transactions, Vol. XIX., p. 926; curves *M. N. R.* in Fig. 9*a*, are reproduced from Fig. 9, of my paper). Now, the acceleration-coefficient is, as is easily shown, nothing more than the tractive effort multiplied by a reduction factor, which we know to be 91.1. This factor (which we may here call *F*), includes the coefficients necessary to change weights from pounds into tons, to convert speeds from feet per second into miles per hour, and to take into consideration the gravity value or measure of acceleration; thus.

$$F = \frac{5280 \times 2000}{3600 \times 32.2} = 91.1$$

Consequently, if, without changing the curve, we change the scale in the ratio of 91.1 to 1, in either of the two curves, they become identical in mathematical character. They both have the same meaning, that is to say, the solid line curve in Fig. 9 of this paper has precisely the same significance as curve M in Fig. 9 of my paper (see Fig. 9*a*). They both express the force which is available, per motor, for producing acceleration. What is still more remarkable is that the solid line curve at the bottom of Fig. 9 of this paper, is identical with the curve R in Fig. 9 of my paper. It is the curve of train resistance expressed in terms of equivalent acceleration. The dotted line curve which is the curve of net acceleration factors is also exactly the same as the curve N in Fig. 9 in my paper. (See Fig. 9*a*). Now, all that is necessary by the point-to-point method, is a curve of that kind (N) and some means for readily determining the reciprocal values. This means is found in what is called, in my paper, the "chart of reciprocals." (Fig. 10 of my paper) which contains several reciprocal curves, by means of which we can get the relation between any speed value and the corresponding time-value. Taking (from the curve N) one of the equivalent acceleration values corresponding to a given speed, we transfer it to the curves that will give its reciprocal; that reciprocal, for a certain increment of speed, will be the corresponding time-increment, when measured by a suitable time-scale.

This time-scale depends on the speed increment (Δv) for which the time increment (Δt) is to be determined. The same reciprocal curve could be made to serve for all speed increments, by suitably changing its scale. It is simpler, in practice, to use a special reciprocal curve for each different speed increment employed in determining the time values. The chart of reciprocals (Fig. 10 of my paper), contains a total of nine such reciprocal curves, which are found sufficient for all speed-increments between .01 and 10 m.p.h.

A method was recently suggested to me for doing this by Mr. L. A. Freudenberger, instructor in physics under Dr. Franklin, at Lehigh University. I had occasion during the past winter, by the kind invitation of Dr. Franklin and Professor Esty, to deliver some lectures on electric train movement at Lehigh University, and Mr. Freudenberger, who attended these lectures, indicated to me his modification of my method, which is of interest in this connection because it is a kind of connecting link between the point-to-point method and analytical methods such as outlined in Mr. Carter's paper.

In my paper, starting from the acceleration-coefficient ($K = \frac{dv}{dt}$), we can easily deduce the fact that the elemental time

value (dt) is equivalent to the reciprocal $\left(\frac{1}{k}\right)$ of that acceleration coefficient, multiplied by the elemental speed (dv), or:

$$dv \times \frac{1}{k} = dt$$

(as given in Appendix C of my paper; see TRANSACTIONS, Vol. XIX., p. 986, equations d and e). Now, Mr. Freudenberger plots, on the same diagram with the curve N (see Fig. 9a), the reciprocals $\left(\frac{1}{k}\right)$ of the equivalent acceleration values, according to the equation just mentioned; and he gets a curve of reciprocals, A (which is shown in Fig. 9a). This curve would have its first portion exactly parallel to the axis of x until it reaches the point b, if the train resistance were constant at all speeds; but, in reality, it will rise slightly as shown in the diagram (Fig. 9a). From the point b, it rapidly changes to an upward course, reaching infinity at the speed-point corresponding to $\frac{dv}{dt} = 0$, which in the case represented in Fig. 9a would be 65.8 m.p.h. Now, knowing that the total time is, of course, equal to the integral

$$\int dt = t = \int \frac{dv}{k}$$

taken between suitable limits, he integrates the reciprocal curve A, and gets a curve of time values (C), which he plots according to a suitable time-scale. If this time-scale is placed on the same axis of coördinates as the "k" values (in Fig. 9a), then the integral curve (C) of the reciprocal curve A, *would be the speed-time curve itself*.

In using this method, Mr. Freudenberger transposes the coördinates of the curve N. He plots this curve with speeds as ordinates and the coefficients (k) as abscissæ, as shown in Fig. 9b. This brings the time values along the axis of abscissæ, and, consequently, leaves the speed-time curve in a more natural position than is the case in Fig. 9a.

The main objection to the method is that it necessitates too many reciprocal curves (A). Every time that there is a change in train resistance, or, rather, in the net tractive effort, owing either to a grade or to a curve, then, evidently, the curve of net acceleration values represented by the dotted line in Fig. 9, also (Curve N in Fig. 9a) changes.

As was pointed out in my paper (see Vol. XIX., p. 929), the effect is the same as if the axis of ordinates were moved upward or downward, according to the case.

It is, therefore, necessary, for each change in condition, to redraw the reciprocal curve A, and to obtain a new integral curve (C) from this new reciprocal curve. While one could draw a set of curves for a large number of conditions, yet, as we have here three quantities, namely, gradients, curves, train resistance,

any one of which may have an indefinite number of values within rather wide limits, and as the same process would be repeated for each change in the motors or in the train load, the result is that it would, in practice, take an indefinitely large number of curves to fit varying cases and conditions, and to give a satisfactory approximation. The method has, therefore, more theoretical interest than practical utility.

A practical difficulty in the use of this method would arise from the mathematical circumstance that the ordinates of the reciprocal curve A approach infinity at the speed values at which the acceleration coefficient (Curve N, Fig. 9a) approaches zero. It will be readily seen that this complicates the process of plotting this curve and of integrating its area. The practical effect is to increase the difficulty of determining the proper time values for the " flatter " portions of the speed-time curves. It was precisely to overcome this difficulty that several reciprocal curves

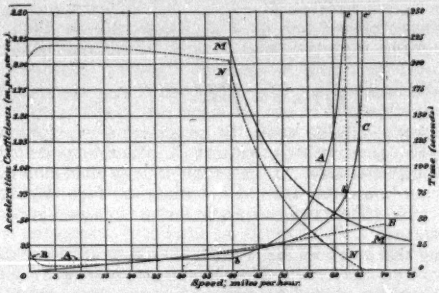


FIG. 9a.

are given in the Chart of Reciprocals (Fig. 10 of my paper). These different curves of reciprocals afford means whereby the " scale " can be changed according to the slope of the speed-time curve, or, in other words, according to the value of the acceleration-coefficient " k." It is obvious, for example, that the portion $(b' - c')$ of the speed-time curve C, which is drawn in dotted line in Figs. 9a and 9b, could not be obtained by integrating the reciprocal curve A according to Mr. Freudenberger's method, unless this curve itself were extended beyond the limits shown in the diagram. The flatter the speed-time curve (C) becomes, the greater will be the extension required in the reciprocal curve (A), whose limiting value is infinity, as already pointed out. The coördinates used for plotting the dotted portion $(b' - c')$ of the curve C, in Figs. 9a and 9b, were readily and quickly determined by using the charts of Coefficients and of Reciprocals, as described in my paper.

I now come to analytical methods such as outlined in the paper. At the last annual meeting, in the discussion of my paper, Mr. S. T. Dodd pointed out the importance of an analytical method, and spoke of his efforts in that direction. In my own discussion I stated that such a method was very desirable and that I hoped to find one. I said that it depended simply upon our finding an analytical or empirical relation between speed and current,

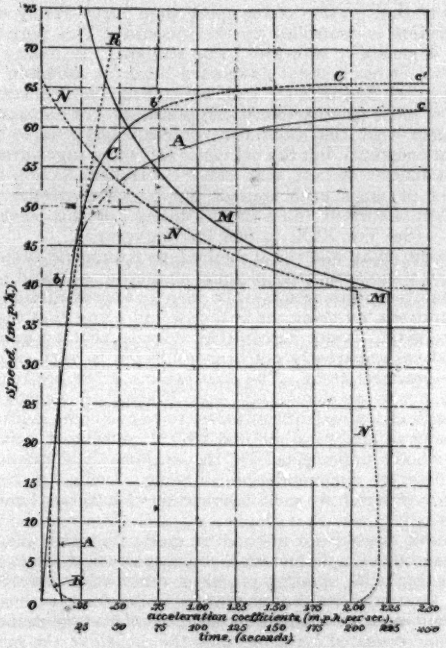


FIG. 9b.

tractive effort and current and also between speed and tractive effort and train resistance. Now, Mr. Freudenberger has made one step in that direction to which I now wish to call attention. Mr. Freudenberger pointed out to me, some three weeks ago, on the occasion of one of my lectures, a fact of which I was not then aware, namely, that Prof. Carus-Wilson had worked out a theoretical or rational method, by means of which the curve (N)

of equivalent acceleration (or net tractive effort, as the author of the paper would perhaps call it), can be expressed analytically with a greater or less degree of approximation. Instead of determining the curve of equivalent accelerations (N), by reference to the data obtained from tests of a motor, Mr. Freudenberger proposed to determine it by a method due to Prof. Carus Wilson, and given in his book, "Electro-Dynamics—The Direct Current Motor." This is an interesting innovation.

The straight portion of the curve (N), it may be stated, corresponds to that portion of the speed-time curve during which the acceleration is controlled by the rheostat. This portion of the curve is generally supposed to be straight. In reality it is not straight; it has a slight downward bend (as shown in Fig. 9a), owing to the fact that the train resistance is not constant. The curve of gross tractive effort (M) is straight (on the assumption, of course, that the rheostatic control is such as to keep the current constant), but the net curve (N) has a slight droop.

As a matter of fact, with motor controllers having a limited number of steps, each step of the motor controller causes a variation of current and a slight "hump" in this portion of the curve. (See Vol. XIX., p. 966, last paragraph).

The aim of an analytical method, as is properly stated in the paper, is to do away with plotting altogether, and still to be able to obtain accurate results—not merely approximations—under all conditions. I think the author would admit that the method as here given, is not susceptible of quite that accuracy. The method has apparently not been subjected to very extensive or severe practical tests. The illustrations given are really quite simple, not to say elementary, cases of speed-time curve plotting, and many of the real difficulties are to be overcome in introducing and using an analytical method are not considered, being apparently wholly unperceived by the author. The method, however, deserves commendation as being a valuable step in the direction in which we must look for the complete solution of the problem.

What is wanted is a method by means of which one can deal with not only simple and abstract, hypothetical, cases and conditions, but with specific, practical, cases and conditions of all kinds, especially those involving complications, such as curves occurring in the middle of a run, necessitating reductions of speed and repeated acceleration in the middle of the run—cases, for instance, such as shown in Fig. 13 of my paper (see Vol. XIX., p. 946). It is, perhaps, well to point out that for such cases—and others still more complicated—the method under discussion would be wholly inadequate, whereas the point-to-point method, or the "interpolation" method described in my paper is entirely adequate.

The analytical method, to sum it up in a few words, requires simply an equation that will enable us to connect the time-values with the speed-values. If we have that, the rest is a mere matter of mathematical manipulation.

Now, the general equation iteslf is a simple one to establish. I worked it out several years ago, and have been hoping to find a method of introducing the functional-coefficients, so as to be able to use it practically. We start from that same equation which we have already derived, which gives us t. If we express speeds (v) in miles per hour and weights in tons of 2000 lbs., and taking $g = 32.2$ and so on, as before, we can easily reduce this to this well-known form:

$$t = 91.1 \int_{v'}^{v''} \frac{dv}{p}$$

where v = m.p.h.

p = net tractive effort in lbs. per ton of 2000 lbs.

If, however, we wish to express it in terms of the difference between the gross and the net tractive effort, the equation takes this form:

$$t = 91.1 \int_{v'}^{v''} \frac{dv}{P \pm G - f - C \pm R}$$

In the denominator we have the total (gross) tractive effort (P) plus or minus grade effect (G), (the sign depending upon whether the grade is "*up*" or "*down*"), minus train resistance effort (f), minus the curve resistance (C). We might add another factor (R), with plus or minus sign, which would indicate the rotative kinetic energy of the train. Now, the integral of that equation would give us the formula connecting t, with v, in any case. The general equation might be written thus:

$$dt = \frac{dv}{(f^k)\ v - (f\lambda)\ v \pm G \pm R - C}$$

The first term in the denominator, the "κ" function of the speed, is nothing more than the equation of the curve of gross tractive effort which is given in Fig. 9 of the present paper, and also of my paper (see Fig. 9*a*). The "λ" function of the speed is the equation of the curve of train resistance. The grade effect (G), the curve effect (C), the rotative and kinetic energy R, are easily and perfectly determinable under all conditions. As this equation shows, we need only two things to be able to predetermine speed-time curves, we need equations for the κ and λ "functions" of the speed, of form such that they can be "substituted" in the general equation. Now, Mr. Carter gets one of them by using a hyperbolic formula to connect speed and tractive effort. In other words, he finds that the speed-tractive effort curve is of hyperbolic type. Unfortunately, he has made certain assumptions by which he sacrifices precision to attain simplicity. Prof. Carus Wilson's method possibly furnishes a more satisfactory formula for the "κ" function. I myself strove

to find an equation connecting the two variables together; but I looked a little further, for I wanted a method of precision, and not merely one of approximation. It is proper to point out here that it is not enough to have the speed-time curve. As shown in my paper, the speed-time curve is only a stepping-stone to the curves which are really of interest and utility—the subsidiary curves, such as the curves of electric current and electric power input and their integral curves, which tell us much that we want to know. Consequently, it is not enough to have a means of plotting speed-time curves. We want more than a means of readily plotting the subsidiary curves—we want a means of obviating the plotting of them, and of obtaining, nevertheless, the results which they would give us and which we now have to obtain by plotting them and laboriously integrating them by mechanical methods. Hence, it is necessary and desirable that we should find not only the curve which connects speed with current, but also the curve which connects tractive effort with the current and also with the speed. Looking at the speed-current and the tractive-effort current curves, one would at once recognize the first as belonging to the hyperbolic family and the other to the parabolic family. It is in that direction I have worked, but I have tried to do it by one type of equation that would fit all cases. Here are two equations of x^n functions: $y = b\,x^n \pm a$: $y = b\,(x \pm a)$. The remarkable mathematical peculiarity of that function is that when n has the negative sign, we have hyperbolas, and when n has the positive sign, we have parabolas, there being an endless number of each, corresponding to the endless series of n values between $+\infty$ and $-\infty$. The effect of a is merely to shift axes of coördinates. In the first equation a serves to shift the axis of y; in the second, it serves to shift the axis of x. The sign is $+$ or $-$ according to the direction in which the axis is shifted. The effect of b (*i.e.*, of variation in b), is merely to change the scale of ordinates. When the scale is the same as for abscissæ, we have $b = 1$, and the equation becomes simplified in form. It can be shown, mathematically, that only one coefficient (b) and only one constant (a) need enter into that equation to enable us to express with a fair degree of accuracy any single branch curve of the hyperbolic and of the parabolic type.

All that is necessary, therefore, is to find out whether the sign of a is positive or negative for these cases, and to determine the most suitable values of b and a. I find that this can be done with relative facility. I have tried it in the case of the speed-current and tractive effort-current curves of a *G E* 65 and of a *G E* 55 motor, and I find that the empirical curves, that is to say, the curves derived by an empirical equation of this "x^n" type, are so close to the original curves that unless the scale is very large, the two curves will coincide fairly well.

The empirical formula takes the form

$$y = b\,(x - a)^n$$

for the curve of tractive effort, and

$$y = b(x-a)^{-n} = \frac{b}{(x-a)^n}$$

for the curve of speeds, when x = current, in amperes (in both cases). With the ordinary scale on which these curves are plotted in the data sheets issued by the manufacturing companies, one would hardly see the difference between the " actual " and the " empirical " curves.

I want to point out that the effect of b, as it enters here, depends mainly upon the gearing ratio and the voltage. It simply has the effect of moving the curves (that is, their ordinates) up or down, in exactly the same way as is done by a change in voltage or in gear ratio. I have not yet fully determined the effect of a. It has apparently some relation to the amount of current required to produce the " friction torque," and possibly also to the resistance of the motor and other things like that.

The formula of Mr. Carter for the speed-current curve is quite as satisfactory as one of the x^n form, and may even have some advantages over it. His formula for the tractive effort curve, however, presumes or assumes a straight line relation, and, consequently, it is unsatisfactory for any method except one of approximation.

The train resistance itself (our " λ " function), after it has been determined by a rational formula (of form which need not be discussed now) can be expressed quite closely, for any given case, by an empirical equation of this (x^n) type.

Mr. Carter finds it desirable, in order to simplify his method, to assume that the train resistance is either constant, or else, may be treated as if it were sub-divided into graded steps. These assumptions are, of course, inadmissible in a method of precision.

If we are able to express the three principal variables, speed, torque, train resistance, by equations of the same type, we can easily find, by an equation of *similar* type, the other relations, such as, for instance, the relation between torque and speed, which is our " κ " function (Curve M). This function can be expressed by a formula of the form

$$y = \frac{b}{x^n}$$

The rest is nothing but a matter of relatively simple mathematical manipulation. It will then be possible to calculate the data for the speed-time curve, also the current and power input curves, and to obtain from them, by *analytical* integration, the distance-time curve, the energy input curve, and various other important subsidiary curves. We will thus obtain the energy value corresponding to a given acceleration cycle, and to any sets of such cycles constituting a " service run." It is also evident that we can then introduce changes of grade, of curvature, train resistance, etc., and, in a word, take into account all the possible conditions and modifications. One can then play all the changes desired upon the " theme," and still have absolutely correct and

determinate results, without any approximations. A complete analytical method will, when it has been developed, enable us to do all this. Mr. Carter deserves much credit for having prepared and presented this paper, which shows important progress in the right direction and contains many useful suggestions, in addition to being, even in its present form, useful for making preliminary, approximative calculations.

[COMMUNICATED AFTER ADJOURNMENT BY MR. C. O. MAILLOUX.]

The method of Mr. L. A. Freudenberger referred to in my discussion of Mr. Carter's paper, has since been made public by its author in two articles printed in the *Electrical World and Engineer*. The first article, entitled, "Plotting of Speed-Time Curve from the Acceleration-Speed Curve," and published in the issue of July 18th (Volume XLII., pp. 96–97). The general description of the method given in this article is substantially as given in my discussion. The second article, entitled, "Plotting of Speed-Time and Speed-Distance Curves from the Acceleration-Speed Curve," and published in the issue of August 9, 1903 (Volume XVII., pp. 219–221), is a continuation of the first communication. This second article contains some interesting extensions and developments of the method, and gives a practical example illustrating the application and use of the method in plotting one of the same Run Curves which was used by me as an illustration in my paper ("Notes on the Plotting of Speed-Time Curves").

The particular run selected by the author as a practical illustration of the use of his method is that described as "Service Run No. 7," illustrated in Fig. 12 of my paper, and described in Volume XIX., on pp. 1079–1088. The reader who is interested in doing so is thus enabled to make a comparison between the two methods, when both are applied to the same case.

The extensions of the method mentioned in Mr. Freudenberger's second article only partly remove the objections to the method, as stated in my discussion. The modified method requires the construction of two accessory curves—one giving the values v/a as a function of the speed, and the other the distance values as a function of the time.

The writer finds by experiment that the modified method does not shorten or simplify the process of plotting a given Run Curve, as compared with the "chart" method described in my paper, and it is, of course, much more laborious than the "Interpolation" method, also described in my paper. The method may, however, be of utility in some cases.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30th, 1903.

INTERURBAN CAR TESTS.

BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

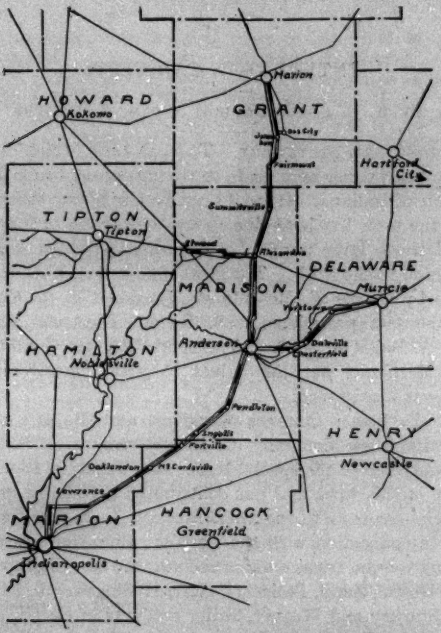
INTRODUCTORY STATEMENT.—The car tests which form the subject of this paper were made on the cars of the Union Traction Company of Indiana. It would not be fair to say that the success of the tests has been due to any one group of individuals, as a relatively large number of experimenters have generously contributed to the work. The great interest taken in interurban practice by George F. McCullough, President of the Company, made the test possible. A. S. Richie, Electrical Engineer, Charles A. Baldwin, Supt. of Transportation, and John Matson, Master Mechanic, put themselves to great inconvenience to render every assistance.

Charles. F. Scott, Clarence Renshaw and B. B. Abry, of the Westinghouse Company are largely responsible for the excellent outcome of the special tests. Mr. Renshaw took a leading part in this work and has contributed a valuable article on the special car tests to the *Street Railway Journal* of October 4, 1902. In connection with the work of calibrating instruments, preparing for the tests, making records and working up results, Messrs. Dostal, Zapp, Peticolas, Hoft, Hollingsworth, Dinsmore, Smith, Starkey and Weaver, senior students in electrical engineering at Purdue University worked hard and well. In the preparation of this paper the results obtained by the various experimentors have been drawn on indiscriminately.

INTRODUCTION.

There are many factors in the problem of interurban electric transportation which have as yet received very inadequate attention. As in all new branches of engineering the first thing sought is successful operation. The economies follow in good

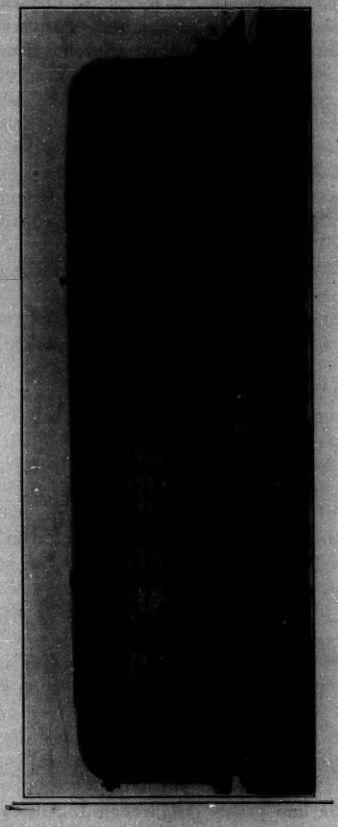
time. Although we are but entering upon the era of interurban electric traction, properties of this nature have come into being so rapidly that by their very weight in numbers they have attained to great perfection in detail on account of the enormous concentration of engineering skill that has been brought to bear on them. This accounts for the fact that we are already aiming at the ultimate economies and the report of which this paper is the subject is but one of many efforts in this direction.



Map of the Union Traction Company's System.

The Union Traction Company of Indiana operates a system extending over five counties and connecting the principal towns between the cities of Indianapolis, Anderson, Muncie and Marion. The system as it stands to-day is a fine example of electric railway engineering and is generally admitted to have been developed along very fine lines. At the time of the tests the Company was operating more than 160 miles of track, 110 miles of which was interurban, the remainder local.

The tests were made on the interurban lines between Indianapolis and Muncie at various times during the springs of 1902 and 1903, although the greater portion of the data was recorded in connection with the general test of the system which occurred

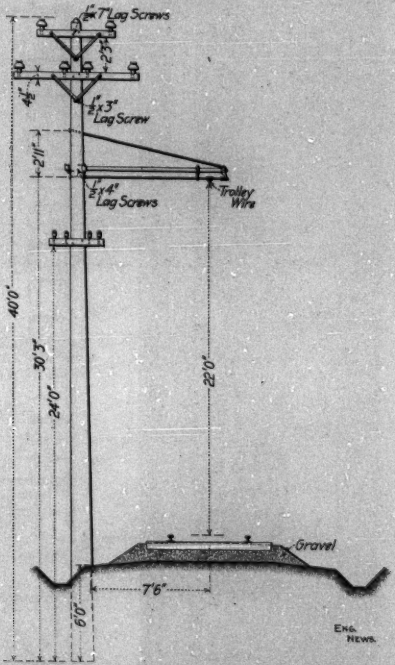


Interurban Car used by the Union Traction Company of Indiana.

April 17, 18, and 19, 1902, and at the time of the special interurban car tests which occurred between March 20th and March 29th, 1902.

The country between Indianapolis and Muncie has a general

appearance of being level. It is, however, quite rolling in part and there are few good level stretches. The interurban road bed is accordingly subject to frequent variations in grade and contains numerous curves. The grades as a rule do not run above 2 per cent. There are a few that run as high as 3 per cent. but they are relatively short. The roadbed is well constructed, the track being made solid with good balasting. Seventy pounds rails are used.



Standard Pole Line Construction of the Union Traction Co. of Indiana.

From Indianapolis the line passes on through Ingalls, and Lawrence to Anderson and from Anderson through Daleville to Muncie. In Table III. the intermediate points are given together with the distances between same.

The interurban trains are of two kinds, those known as local trains and those known as through or limited trains. The first

stop at all towns and at frequent intermediate points or for flag stations; the rule being that the local trains will stop to pick up passengers at any point where a county road crosses the interurban track. The limited cars work on a through schedule between Indianapolis and Muncie, stopping only at Anderson.

The trains are controlled through a very well developed train dispatching system. All the motormen receive their instructions from and report to the train dispatcher at frequent telephone connection boxes along the track. To put himself in communication with the train dispatcher it is only necessary for the motorman to insert his telephone plug into the connections of the telephone box without leaving his car, as each car is equipped with a telephone set. The train schedule is carefully worked up and all cars are required to run exactly on time.

Power is delivered at 550 volts to the interurban trains on the Indianapolis Muncie Division from substations located at Lawrence, Ingalls, Anderson, Daleville and Muncie. The main power station is located at Anderson, and supplies energy over a high-tension, three-phase transmission system to rotaries in the various substations.

The cars used on the Indianapolis Muncie Division are all of the same type. They are 52 feet 6 inches over all and weigh 63,100 pounds. The motive power equipment of these cars consists of two number 50 C motors, which are mounted on the forward truck and are nominally rated at 150 h.p. each. The motors are geared with the ratio of 20 to 51 and are geared to 36 inch wheels. Records were obtained from 10 cars of this type and also from two other cars differently equipped. As the latter were only used in the special tests they have no bearing on the general tests made on April 17th, 18th and 19th.

General Car Tests.

In making preparations for the general tests, the first thing necessary was to secure sufficient ammeters and voltmeters, and recording wattmeters of the railway car type. Finally the details were arranged, and at the time of the test each car was fitted with a Thompson recording car wattmeter and also with a Westinghouse ammeter and voltmeter. The instruments were placed on the left hand wall of the motorman's vestibule and hence were very easily accessible for reading. The wattmeters were all calibrated in position on the cars by the following method: A voltmeter and ammeter previously standardized were used to calibrate the Westinghouse voltmeters all connected in parallel and the Westinghouse ammeters all connected in

CONSUMPTION CURVES.
Trains No. 5, 7, 11, 13, 19, 27, 29, 35, 41
Indianapolis to Muncie
April 17, 1902.
Peloubet & Roth.

FIG. 1

CONSUMPTION CURVES.
Trains No. 6, 12, 14, 20, 26, 40, 42, 46.
Muncie to Indianapolis.
April 17 1902.
Peloubet & Roth.

FIG. 2

series. The ammeters and voltmeters were then placed on the cars and used in calibrating the car wattmeters.

Between Muncie and Indianapolis the different cars were taken in turn by two observers and readings of the voltmeter and ammeter were recorded as rapidly as possible between stops. Simultaneously with these readings, readings were taken of the time and of the rate of rotation of the wattmeter disk. From the data thus accumulated the wattmeter constants were checked.

The objects of the general tests on the interurban and limited cars were:

First.—To determine in detail the k.w. hour consumption of individual cars, both local and limited, between stated points, en route from Muncie to Indianapolis and vice versa.

Secondly.—To average these results and to determine as well the maximum and minimum k.w. hour consumption over the route.

Thirdly.—To ascertain in so far as possible the general effect of starts and the personality of the motormen as factors in car consumption economy.

In accumulating data for these purposes, an observer was placed on each of the interurban cars operating between Indianapolis and Muncie throughout the three days of the general test. These observers were instructed to take wattmeter readings at all stops, at all circuit breakers and to read both ammeter and voltmeter at intervals of every fifteen minutes.

The results of their work on April 17th is shown in part in the curves of Fig. 1, 2, 3 and 4; and in Table I. is given the record of all of the trains operated east and west on this day. The curves of Fig. 1 are interesting from the fact that they show the progressive increase in the energy consumption of the cars quite perfectly. It is noticed in general that while operating within the city of Indianapolis, the consumption per mile is greater than where the cars are running through the country. An increase in the slant of the consumption curves is also noticeable when the cars are running through Muncie at the end of the trip, but is not so pronounced as in Indianapolis. The cycle of events can be followed quite accurately in the case of most of the cars; for instance, taking train number 13 which consists of car number 254, we find that until it reaches siding 27, which is at the limits of Indianapolis, the rate at which energy is consumed is quite high; after leaving siding 27 the rate of consumption falls off somewhat, but increases again between sidings 25 and 24.

TABLE I.

CONSUMPTION PER CAR. EAST AND WEST.

EAST BOUND.			WEST BOUND.		
Train.	Car No.	K.W.H.	Train.	Car No.	K.W.H.
		LOCAL CARS.			
1	246	131.2	2	260	122.4
3	262	111.0	4	263	140.0
5	264	148.0	6	254	142.5
7	260	130.6	8	261	142.0
9	...	.....	10	...	.....
11	263	124.5	12	246	128.5
13	254	137.6	14	262	122.0
15	260	127.5	16	260	114.2
17	...	.....	18	...	.....
19	246	125.6	20	263	135.5
21	262	123.0	22	254	139.2
23	260	133.5	24	261	132.8
25	...	.....	26	...	.....
27	263	.....	28	246	134.8
29	254	162.0	30	262	127.0
31	261	146.5	32	252	139.5
33	...	.....	34	...	.....
35	246	119.0	36	264	141.5
37	262	112.5	38	260	128.5
39	252	128.7	40	263	134.0
41	254	119.0	42	254	126.0
43	263	118.5	44	252	113.1
	Min., 111.0 Ave., 129.2 Max.,162.0			Min., 113.1 Ave., 131.3 Max., 142.5	
		LIMITED CARS.			
9	250	107.4	10	255	101.0
17	255	96.0	18	250	123.8
25	250	108.5	26	255	106.0
33	255	101.0	34	250	119.6
	Min. 96.0 Ave., 103.2 Max., 108.0			Min., 101.0 Ave., 112.6 Max., 123.0	

TABLE II.

TRAIN LOG.

Train No.	Car No.	Direction.	K. W. H.	K. W. H. Per Car Mile.
1	246	East	131.2	2.32
12	246	West	128.5	2.28
19	246	East	125.6	2.21
28	246	West	134.8	2.38
35	246	East	119	2.11

TABLE II.—Continued.

Average, East				2.21
Average, West				2.33
9L	250	East	107.4	1.9
18L	250	West	123.8	2.19
25L	250	East	108.5	1.92
34L	250	West	119.6	2.11
Average, East				1.91
Average, West				2.15
39	252	East	128.7	2.27
32	252	West	139.5	2.46
44	252	West	113.1	2.00
Average, East				2.27
Average, West				2.23
6	254	West	142.5	2.52
13	254	East	137.6	2.43
22	254	West	139.2	2.46
29	254	East	162	2.86
41	254	East	119.0	2.10
42	254	West	126	2.23
Average, East				2.46
Average, West				2.40
10L	255	West	101.0	1.77
17L	255	East	96.0	1.70
26L	255	West	106.0	1.87
33L	255	East	101.0	1.78
Average, East				1.74
Average, West				1.83
2	260	West	122.4	2.16
7	260	East	130.6	2.30
15	260	East	127.5	2.25
16	260	West	114.2	1.85
23	260	East	133.5	2.35
38	260	West	128.5	2.27
Average, East				2.30
Average, West				2.09
31	261	East	156.5	2.59
8	261	West	142.0	2.51
24	261	West	132.8	2.34
Average, East				2.59
Average, West				2.42
30	262	West	127.0	2.24
3	262	East	111.0	1.96
14	262	West	122.0	2.15
21	262	East	123.0	2.17
37	262	East	112.5	1.98
Average, East				2.03
Average, West				2.19
11	263	East	124.5	2.20
20	263	West	135.5	2.39
27	263	East	94.5	2.48
40	263	West	134.0	2.37
43	263	East	118.5	2.09
4	263	West	140.0	2.48
Average, East				2.26
Average, West				2.41

TABLE II.—Continued

5	264	East	148.0	2.61
36	264	West	141.5	2.49

L indicates limited trains.

TABLE III.

LOCAL CAR NO. 260 EAST BOUND. K.W.H. CONSUMPTION.

Station.	Distance	K.W.H. Between Stations			W.K.H. per Car Mile		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Indianapolis	3.4	9.9	10.8	12.3	2.91	3.18	3.62
Indianapolis E.	7.4	18.9	19.1	19.2	2.55	2.58	2.60
Lawrence	11.4	18.3	22.8	27.1	1.61	2.00	2.38
Fortville	2.8	7.2	7.9	9.0	2.57	2.82	3.18
Ingalls	4.7	7.0	7.9	9.0	1.49	1.68	1.82
Pendleton	8.0	16.8	18.1	18.9	2.10	2.26	2.36
Anderson W.	1.2	4.5	5.2	5.8	3.75	4.34	4.84
Anderson E.	6.5	9.5	11.7	13.8	1.46	1.80	2.12
Daleville	5.1	10.2	10.3	10.5	2.0	2.02	2.06
Yorktown	6.0	15.0	15.0	15.1	2.50	2.50	2.51
Muncie							
Indianapolis	56.5	117.3	128.8	140.6	2.07	22.8	2.48
Muncie							

TABLE IV.

LOCAL CAR NO. 260, WEST BOUND. K.W.H. CONSUMPTION.

Station.	Distance.	K.W.H. Between Stations			K.W.H. Per Car Mile.		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie	6.0	11.8	13.7	15.1	1.97	2.29	2.50
Yorktown	5.1	7.3	11.0	16.0	1.43	2.15	3.14
Daleville	6.5	13.6	13.7	13.8	2.09	2.11	2.12
Anderson E.	1.2	2.5	3.7	4.5	2.08	3.08	3.76
Anderson W.	8.0	13.3	16.7	19.1	1.66	2.09	2.39
Pendleton	4.7	9.3	10.6	12.6	1.98	2.26	2.68
Ingalls	2.8	5.1	5.8	6.9	1.76	2.00	2.38
Fortville	4.8	8.0	8.9	9.9	1.66	1.86	2.06
McCordsville	6.6	13.5	14.6	16.6	2.05	2.21	2.53
Lawrence	7.4	12.8	14.1	16.4	1.73	1.91	2.22
Indianapolis E.	3.4	8.5	10.2	11.9	2.50	3.00	3.50
Indianapolis							
Muncie	56.5	105.7	123.0	142.8	1.87	2.18	2.52
Indianapolis							

CONSUMPTION CURVES
Limited Trains No. 17, 9, 19, 23
Indianapolis to Muncie
April 27, 1903.
Peirce & Smith.
FIG. 3
Kilo-Watt Hours
Distance in Miles
Indianapolis
Ole. Brewster
Station 2
Station 3
Stations
Station 4
Irvington
Station 10
Cheesterfield
Ole. Brewster
Anderson
Station 11b
Station 12
Station 13
Pendleton
Station 15
Ingalls
Fortville
Station 19
McCordsville
Daleville
Station 22
Lapreton
Station 24
Station 25
Muncie

CONSUMPTION CURVES
Limited Trains No 16, 18, 20, 24
Muncie to Indianapolis
April 27, 1903.
Peirce & Smith.
FIG. 4
Kilo-Watt Hours
Distance in Miles
Muncie
City Brewster
Station 1
Station 2
Tretsown
Station 4
Irvington
Cheesterfield
City Brewster
Anderson
Station 11b
Station 18
Pendleton
Station 15
Ingalls
Fortville
Station 19
McCordsville
Daleville
Station 22
Lapreton
Station 24
City Brewster
Indianapolis

The car runs through Lawrence with relatively small energy consumption and continues at about the same rate until the western limits of Anderson are reached. In passing through Anderson there is quite a considerable increase in the energy consumption of the car. West of Anderson the rate of consumption returns to normal until siding 3 is reached where in working in and out of the siding a considerable amount of power is required. From siding 3 the car runs into Muncie under a normal amount of energy per car mile.

The schedule speed of local trains between Indianapolis and Muncie is 23 miles per hour; on clear stretches running through the country the speed frequently runs up to 50 miles per hour, but in general, averages about 38 miles per hour. In the towns, however, a slower rate of speed is required, which brings the schedule in the country to 27 miles per hour. When operating within the city limits of Anderson and Muncie 20 miles an hour are not, in general, exceeded, and, in Indianapolis the rate varies from 20 miles in the suburbs to 10 miles in the business districts. The schedule speed in Indianapolis is 10.28 miles. The slower speeds within the towns together with the frequent stops made therein account for the greater consumption within city limits.

The curves of Fig. 2 show an improvement in the operation of the local trains going west, for the reason that the consumption curves bunch together much better and show a less variation from the mean.

What has just been said regarding local trains must be reversed in comparing the consumption curves of the limited trains, shown in Figs. 3 and 4. The curves for the limited trains running east on April 17th follow one another very closely and indicate but slight variations in the power consumption per car mile per train. In the case of the trains running west, however, the car consumption of train 34 is considerably higher than that of train 10, and variations in the rate of energy consumption are much greater in the case of the cars running west than in the case of those running east. The fact that the eastern limited trains are usually given right-of-way at the sidings, has much to do with these variations; the number of stops per trip of the west bound limited trains being in general in excess of the number of stops per trip of the east bound limited trains. The speeds attained by the limited trains run as high as 60 miles an hour. Speeds as high as 52 and 53 miles an hour are frequent.

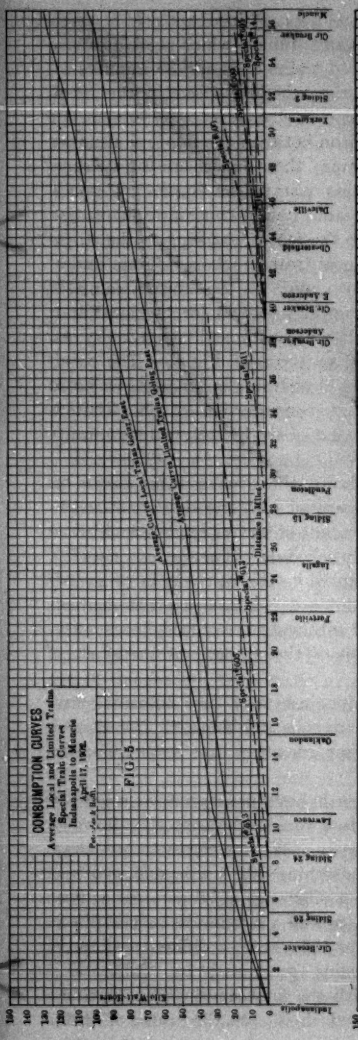

CONSUMPTION CURVES
Average Local and Limited Trains
Special Train Curves
Indianapolis to Muncie
April 17, 1903.
Patches & Rich
Kilo-Watt Hours
Distance in Miles
Indianapolis
City Hospital
31st St.
26th St.
24th St.
Lawrence
Oak Grove
Speedway
Clermont
Clermont
Speedway
Oak Grove
Lawrence
24th St.
26th St.
31st St.
City Hospital
Indianapolis
Average Curve Local Trains Going East
Average Curve Limited Trains Going East
Special Car No. 13
Special Car No. 15
Special Car No. 14
Special Car No. 16
Average Curve Limited Trains Going West
Average Curve Local Trains Going West

FIG. 5

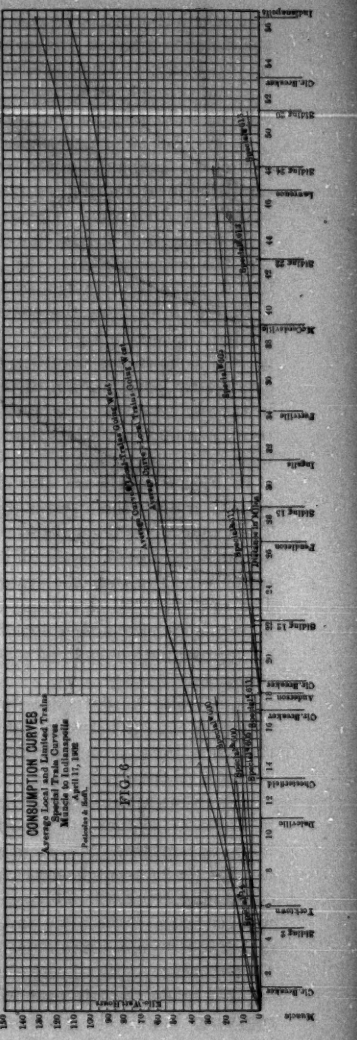

CONSUMPTION CURVES
Average Local and Limited Trains
Special Train Curves
Muncie to Indianapolis
April 17, 1903
Patches & Rich
Kilo-Watt Hours
Distance in Miles
Muncie
City Hospital
21st St.
Tottown
Clermont
Clermont
Tottown
21st St.
City Hospital
Muncie
Average Curve Local Trains Going West
Average Curve Limited Trains Going West
Special Car No. 13
Special Car No. 15
Special Car No. 14
Special Car No. 16
Average Curve Limited Trains Going East
Average Curve Local Trains Going East

FIG. 6

The schedule speed is 28 miles an hour. Since cars have to cover the distance between Anderson and Muncie, which is 56.55 miles, in two hours, and as the limited trains consume 35 minutes in passing through city streets, the schedule speed in the open country is 35 miles an hour.

In Fig. 5 is shown a comparison between the power consumption of the local and limited trains; these curves are the average of all the local and limited trains operated on April 17th, going east from Anderson. The greater power consumption of the local trains is, of course, due to the fact that owing to the stops and the longer schedule, the local trains took two hours and a half to make the trip against two hours by the limited trains.

In Fig. 5 we have the consumption curves for the local and limited trains running west. It will be noticed that the curves in Fig. 6 lie closer together than those of Fig. 5. The total average car consumption of the local trains is the same in both instances, whereas, the average consumption of the limited trains running east is less than that of the limited trains running west.

In Figs. 5 and 6 are also shown the consumption curves of special trains which were operated on the day mentioned. These give a good idea of the amount of service rendered which is not included in the regular daily schedule. The special or work-trains were run over the system while the test was in progress. The cars were all small and did not consume a great deal of power; they were not equipped with wattmeters, and, hence, only an approximation could be made of the amount of energy they consumed.

It is quite hard to determine just why the different cars will make the run between Indianapolis and Muncie in parctically the same time, and on different runs consume such different amounts of energy

The trains scheduled in Table I. have been grouped together in Table II. so that a comparison can be made of the kilowatt hour consumption of different runs. We find, for instance, that car 254 made one trip east consuming 162 k.w.h. and another consuming 119 k.w.h. which is a difference of 36 per cent. The western trips on the same day showed a maximum consumption of 142 k.w.h. and a minimum of 126 k.w.h., a difference of only 13 per cent. Of all the trains scheduled in Table II., car 262 made the trip east with the least energy consumption, requiring but 111 k.w.h., which is at the rate of 1.96 k.w.h. per car mile. The highest consumption by this

car is 123 k.w.h., or an increase of only 10 per cent. The number of stops made by a car on different trips undoubtedly has quite an effect upon the amount of energy consumed. The greater the number of stops the greater the amount of time deducted from the regular running time, and, the greater must be the acceleration of the train to enable it to make up the lost time. This is quite clearly brought out by the fact that the limited trains, as shown in Table I., average on their eastern trips only 103 k.w.h., whereas the local trains average 129 k.w.h. on their eastern trips, an increase of 35 per cent. As a rule the limited trains after leaving Indianapolis only stop once at Anderson in their run to Muncie. Going west the limited trains usually pull in at sidings to allow east bound trains to pass. This probably accounts for the fact that the k.w.h. consumption of the west bound limited trains is somewhat greater than the k.w.h. consumption of the east bound limited trains, although the west bound limited trains are relatively running down grade, Muncie having an elevation of about 100 feet above Indianapolis.

The number of stops made by the local cars outside of the cities averages about 34.

An average taken of the runs made by the local cars, east and west, shows them to be very much the same. For instance, in Table I., the average of the east bound locals is 129 k.w.h. and of the west bound, 131, k.w.h.; practically the same.

The best run going east shows a car consumption of 111 k.w.h. by car number 262; the highest car consumption going east is 162 k.w.h. by car number 254, a difference of 49 per cent. The average of the eastern trips made by car number 262 is 115 k.w.h., and the average of the trips made by car 254 is 139 k.w.h., a difference of 21 per cent. As the two cars are of the same weight and equipment, and as the runs made by them are spaced sufficiently close together to admit of the supposition that the average stops made during the day by the two cars is very much the same, we have to assume that the difference in power consumption is caused by the equipment of car number 262 being in better condition than that of car number 254 as the personal equation of the motorman in the operation of his car in local interurban service, as will be shown later, is practically without effect where a number of runs are taken into consideration. Among the west bound local trains, car 254 shows again the highest consumption, which seems to make it quite conclusive that its running gear was affected in some particular. Here we have a case in point in which causes other than the number of starts made during a

trip having had the effect of causing a decided increase in the power consumption of a car. We cannot, therefore, charge up discrepancies in energy consumption entirely to the number of starts made. It is fair to say, however, that each start requires the expenditure of from .5 to .8 k.w.h.

In the case of the limited runs we find by reference to Table I. a variation of 13 per cent. in the energy taken by the east bound trains and a variation of 22 per cent. in the energy taken by the west bound trains.

In connection with the general discussion of the amount of power required to operate these trains it has been thought of value to study the results obtained from the operation of a given car over a series of trips in detail. Car 260 has accordingly been made the subject of this analysis. From Table II. it will be noticed that car number 260 made six local trips between Indianapolis and Muncie, three east and three west, on April 17th, which are distributed entirely through the day. The car may therefore be assumed to represent fairly well the average daily cycle through which a local car has to pass.

In Tables III. and IV. the analysis of the performance of this car is presented. In Table III. the column which shows the average k.w.h. consumption between stations gives the average energy consumption of the car for the three trips made from Indianapolis to Muncie. The column to the right of this headed "maximum" gives the maximum consumption between the different stations that occurred in any one of the three eastern trips and the column headed "minimum" gives the minimum consumption that occurred on any one of the three trips east to operate the car between the stations.

The "average" column may therefore be said to represent the average daily performance of the car. The "maximum" column gives the probable amount of power which the car is likely to use in passing between stations and the "minimum" column gives what is probably the least amount of energy which this car is likely to take in passing between stations, in local service. The footings of these columns give accordingly the probable maximum, the average ordinary and the probable minimum energy which the car will take in making a trip from Indianapolis to Muncie.

The maximum, 140.6 k.w.h., is 9 per cent. in excess of the average and 12 per cent. in excess of the minimum. The greatest differences between the maximum and minimum values occur in the runs between Lawrence and Fortville, and Anderson

E. and Daleville. The variations between the maximum and minimum values between Daleville and Muncie are relatively immaterial. In running between Lawrence and Fortville the maximum value is 47 per cent. in excess of the minimum and in running from Anderson E. to Daleville the maximum is 45 per cent. in excess of the minimum.

The average for the trip (in Table III.) is 128.8 k.w.h. The average of the three actual eastern trips of car 260 given in Table II. is 130.5, showing that the sum of the average energy consumptions of several runs taken between stops is 1.5 per cent. less than the actual average of the three runs. In Table IV. a similar set of tabulations is made for the three west bound trips of car 260 and results that do not markedly differ from those of Table III. are shown. For instance, the average energy consumption in Indianapolis east bound is 10.8 k.w.h. against 10.2 west bound. The average energy consumption in Muncie is 15 k.w.h. east bound against 13.7 west bound. The average energy consumption in Anderson is 5.2 east bound against 5.1 west bound.

The greatest difference in the averages is shown in those taken for the runs between Indianapolis E. and Lawrence; the average of the east bound trains, 19.1 k.w.h., being 49 per cent. in excess of the average of the west bound trains between these points. The greatest variations between the maximum and minimum consumption between stations in Table IV. occurs in the runs between Yorktown and Daleville, where the variation is 119 per cent.

As regards the energy consumption for the trip, we find that the average of the east bound trains exceeds the average of the west bound trains by 4.5 per cent.; and that the maximum probable energy consumption of east bound trains is 142.8 k.w.h., which is 35 per cent. in excess of the minimum and 16 per cent. in excess of the average.

The three columns at the left of Tables III. and IV. refer to the consumption of car 260 in k.w.h. per car mile.

It is noticeable that the maximum rate of energy consumption in all cases occurs in the cities. The energy consumption per car mile in Anderson being greatest, in Muncie least and in Indianapolis more or less of an average between the other two places. This increase in the energy consumption in the cities is due to the slower speeds, frequent stops and very often to low voltage. It will be noticed that the maximum energy consumption in Anderson is 4.84 k.w.h. per car mile, whereas in Indianapolis it is only 3.62 k.w.h. per car mile.

TABLE V.

LOCAL CAR CONSUMPTION FOR VARIOUS SECTIONS OF LINE. EAST BOUND.

Station.	Distance.	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max
Indianapolis							
	3.4	9.4	11.9	14.6	2.76	3.50	4.30
Indianapolis E.							
	7.4	13.8	18.9	25.5	1.86	2.55	3.45
Lawrence							
	11.4	13.7	22.8	29.0	1.20	2.00	2.55
Fortville							
	2.8	5.2	7.1	8.1	1.86	2.53	2.89
Ingalls							
	4.7	7.0	9.5	12.5	1.49	2.02	2.66
Pendleton							
	8.0	16.1	19.8	24.1	2.01	2.47	3.01
Anderson W.							
	1.2	4.0	5.3	8.2	3.40	4.42	6.82
Anderson E							
	6.5	9.0	12.4	17.2	1.38	1.91	2.65
Daleville							
	5.1	7.0	8.7	12.2	1.37	1.71	2.39
Yorktown							
	4.7	7.4	10.4	12.3	1.57	2.21	2.61
Muncie W.							
	1.3	2.5	5.2	9.9	1.92	3.99	7.60
Muncie							
TOTAL TRIP	56.5	95.1	132.0	173.6	1.68	2.34	3.06
TOTAL URBAN	5.9	15.9	22.4	32.7	2.70	3.79	5.54
TOTAL INTERURBAN	50.6	79.2	110.4	140.9	1.56	2.18	2.79

TABLE VI.

LOCAL CAR CONSUMPTION FOR VARIOUS SECTIONS OF LINE. WEST BOUND.

Station.	Distance.	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
	Miles.	Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie							
	1.3	2.5	5.2	9.9	1.92	3.99	7.6
Muncie W.							
	4.7	7.8	10.8	15.3	1.66	2.29	3.25
Yorktown							
	5.1	7.3	13.1	16.8	1.43	2.57	3.29
Daleville							
	6.5	9.2	13.7	15.7	1.42	2.10	2.42
Anderson E.							
	1.2	2.5	4.4	6.1	2.08	3.66	5.09
Anderson W.							
	8.0	15.4	19.2	23.3	1.93	2.40	2.92
Pendleton							
	4.7	7.0	10.6	15.0	1.49	2.26	3.19
Ingalls							
	2.8	5.1	6.6	8.4	1.82	2.35	3.00
Fortville							
	11.4	17.0	24.2	28.5	1.49	2.12	2.50
Lawrence							
	7.4	12.0	15.5	22.3	1.67	2.15	3.10
Indianopolis E.							
	3.4	7.5	11.5	18.6	2.21	3.38	5.47
Indianapolis							
TOTAL TRIP	56.5	93.3	134.9	179.9	1.65	2.37	3.18
TOTAL URBAN	5.9	12.5	21.1	34.6	2.12	3.57	5.88
TOTAL INTERURBAN	50.6	80.8	113.8	145.3	1.60	2.24	2.87

The least energy consumption per car mile shown in these tables is on one of the westward trips between Yorktown and Daleville, where as low a value as 1.43 k.w.h. per car mile is shown. This is but 30 per cent. of the maximum consumption cited for the eastern trip in Anderson.

In Tables V. and VI. a still more elaborate study has been made of power consumption between points. These tables include a regimé of all of the data accumulated for all of the cars on April 17th. For instance, the table of east bound consumption gives in the average column the average consumption between points for all of the cars, the minimum column gives the least consumption recorded between points for any one of the cars and the maximum gives the maximum consumption for any one of the cars.

Comparing these results we see that in running through Muncie the power consumption per car mile varies from 2.5 to 9.9, a variation of 300 per cent. Differences exceeding 100 per cent. are quite frequent, as for instance between Indianapolis E. and Lawrence and between Lawrence and Fortville and in Anderson. Since all of the cars are of about the same weight and equipped in the same way, it is quite evident that even in the local runs much could be done to improve the character of the operation, especially if the motormen were carefully instructed in the detail handling of their cars.

The values given in the maximum column are the exceptionally high values. They reach a total of 173.6 k.w.h. This value is in excess of any of the east bound trips given in Table I. and is even higher than the power required by car 254 in trip 29, which is in itself 25 per cent. higher than the average of all the eastern trips for that day. The run of car 254 indicates the degree to which very bad conditions are sometimes approximated. Any motorman who should continually operate his car making a demand as high as the maximum values given in Tables V. and VI., that is 173 to 180 k.w.h. per trip, should be dsicharged.

The minimum value per trip given in Table V. of 95.1 k.w.h. is 16.5 per cent. less than the minimum for any local trip in Table I. and is even 1 per cent. less than the minimum consumption, 96 k.w.h., made in the best eastern trip of a limited car. Ninety-five k.w.h. is therefore probably less than the minimum value that any car will ever take in a local trip between Indianapolis and Muncie. This is 49 per cent. less than the average and 83 per cent. less than the maximum k.w.h. consumption per trip

given in Table V. In all of the values given in Table V. it is quite noticeable that the difference between the minimum and the average is less than the difference between the average and the maximum. This indicates that the motormen, in general, handle their cars creditably.

The composite presentation of the data of all west bound trains given in Table VI. tells much the same story as does Table V. The best performance per trip of 93.3 k.w.h. betters the best performance of Table V. as does also the best performance of car 260 west bound better its best performance east bound. In the same way the maximum of 179.9 k.w.h. is greater than the maximum for the total trip of Table 5. Car 260 shows this same result; the western maximum per trip being 2 k.w.h. larger than the eastern maximum per trip.

There would therefore seem to be something in the contour of the road which develops greater irregularities in operation when cars are running west than when they are running east. These conditions are not very marked yet sufficiently so to be noticeable. They cannot be traced especially to the cities as against interurban operation. At the bottom of Tables V. and VI. the urban and interurban power consumption is separated and for all of these results the minimum and maximum values of Table VI. are respectively less and greater than the minimum and maximum values of Table V.

The urban and interurban data, however, brings out very clearly the fact that within the city limits the car consumption per car mile is considerably greater than in running through the country. The maximum values for city service run as high as 7.6 k.w.h. per car mile and average 5.88 k.w.h., whereas in the country the maximum value either east or west does not exceed 3.45 k.w.h. per car mile and average not more than 2.87 k.w.h. per car mile. The values given in the column of averages show best the relative performance of cars in urban and interurban service. During the east bound trips the urban cars on the average consumed 17 per cent. of the energy running 10.4 per cent. of the distance, their power consumption in the cities per car mile being on the average 74 per cent. in excess of what it was in the country.

In Table VI. it is shown that while running but 10.4 per cent. of the distance in the cities, the west bound trains consumed 15.5 per cent. of the energy; their car mile consumption being 60 per cent. higher in urban than in interurban service. To make the comparison between the average energy consumption of the cars

when east and west bound more complete, the average values are brought together in Table VII. This table shows that trains running east and west require approximately the same power when running through the cities, the greatest variations occurring in the interurban service. The run between Daleville and Yorktown is most noticeable in this respect, power consumption going west being 43 per cent. greater than the average power consumption of trains going east. The general averages given at the bottom of the page show quite clearly that the local trains require under average conditions the same amount of power whether running eastward or westward.

Passing from the local trains, we have gathered together in Tables VIII., IX. and X. a comparison of the performance of all the limited trains in service. The most noticeable thing in connection with the data here given is that the variations in the energy consumption per trip in the limited service are very much less than those in the local service. As between the different runs by limited cars, the tables show again that the differences in the consumption of east bound trains are less than the differences in the consumption of west bound trains. It will be remembered that the same notation has been made in discussing the performance of car number 260 as that of all the local trains. The minimum possible energy consumption per trip whether east or west is 95 k.w.h., or practically the same as that given for the local trains. The fact that the limited runs show up so much better than do the local runs is undoubtedly due to the number of starts in the limited trips being very much less, the limited cars having the right-of-way and the best motormen being in charge of them. These three items taken collectively account for a great deal.

It will be noticed by reference to Table VIII. that the energy consumption by cars between Indianapolis East and Anderson West is practically the same and that there is but 25 per cent. difference in the energy consumption when the cars are running between Anderson East and Muncie West. It must be remembered that this percentage indicates the maximum difference that occurred between any two cars at any time.

The variation in the energy consumption of the cars running through the cities does not vary in excess of 50 per cent. between the maximum and minimum values. Whereas, it will be remembered that in the case of the local cars differences as great as 300 per cent. are recorded. The maximum urban consumption per

TABLE VII.

(See Tables V. and VI.)

COMPARISON OF AVERAGE LOCAL CAR CONSUMPTION OVER CERTAIN SECTIONS OF THE LINE.

Section.	Distance Miles.	Average Consumption.			
		K.W.H. Between Stations		K.W.H. Per Car Mile	
		East.	West.	East.	West.
Indianapolis	3.5	11.9	11.5	3.50	3.38
Indianapolis E.	7.4	18.9	15.5	2.55	2.15
Lawrence	11.4	22.8	24.2	2.00	2.12
Fortville	2.8	7.1	6.6	2.53	2.35
Ingalls	4.7	9.5	10.6	2.02	2.26
Pendleton	8.0	19.8	19.2	2.47	2.40
Anderson W.	1.2	5.3	4.4	4.42	3.66
Anderson E.	6.5	12.4	13.7	1.91	2.10
Daleville	5.1	8.7	13.1	1.71	2.37
Yorktown	4.7	10.4	10.8	2.21	2.29
Muncie W.	1.3	5.2	5.2	3.99	3.99
Muncie					
TOTAL TRIP	56.5	132.0	134.9	2.34	2.37
TOTAL URBAN	5.9	22.4	21.1	3.79	3.57
TOTAL INTERURBAN	50.7	110.4	113.8	2.18	2.24

TABLE VIII.

LIMITED CAR CONSUMPTION FOR VARIOUS SECTIONS OF LINE. EAST BOUND.

Station.	Distance Miles.	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
		Min.	Ave.	Max.	Min.	Ave.	Max.
Indianapolis	3.4	8.1	8.7	10.3	2.38	2.56	3.03
Indianapolis E.	34.4	56.5	58.0	59.9	1.64	1.69	1.74
Anderson W.	1.2	3.4	4.2	4.8	2.84	3.50	4.00
Anderson E.	16.3	24.0	28.5	30.6	1.47	1.75	1.88
Muncie W.	1.3	3.0	3.6	4.4	2.31	2.77	3.38
Muncie							
TOTAL TRIP	56.6	95.0	103.0	110.0	1.68	1.82	1.94
TOTAL URBAN	5.9	14.5	16.5	19.5	2.46	2.80	3.30
TOTAL INTERURBAN	50.7	80.5	86.5	90.5	1.59	1.71	1.79

TABLE IX.
LIMITED CAR CONSUMPTION FOR VARIOUS SECTIONS OF LINE. WEST BOUND.

Station.	Miles	K.W.H. Between Stations.			K.W.H. Per Car Mile.		
		Min.	Ave.	Max.	Min.	Ave.	Max.
Muncie							
	1.3	3.5	4.4	5.1	2.49	3.38	3.92
Muncie W.							
	16.3	27.1	29.9	32.3	1.66	1.83	1.98
Anderson E.							
	1.2	3.9	4.6	5.3	3.25	3.84	4.42
Anderson W.							
	9.9	16.9	19.6	22.8	1.71	1.98	2.31
Siding 15							
	7.6	13.5	14.9	16.5	1.78	1.96	2.17
Siding 19							
	16.8	16.7	25.0	33.0	.99	1.49	1.96
Indianapolis E.							
	3.4	8.9	11.2	13.9	2.61	3.29	4.09
Indianapolis							
TOTAL TRIP	56.5	90.5	109.6	128.9	1.60	1.94	2.28
TOTAL URBAN	5.9	16.3	20.2	24.3	2.76	3.60	4.12
TOTAL INTERURBAN	50.6	74.2	89.4	104.6	1.47	1.77	2.07

TABL X.
(See Tables 8 and 9.)
COMPARISON OF AVERAGE LIMITED CAR CONSUMPTION OVER CERTAIN SECTIONS OF THE LINE.

Section.	Distance Miles.	Average K.W.H. Consumption.			
		K.W.H. Between Stations		K.W.H. Per Car Mile.	
		East.	West.	East.	West.
Indianapolis					
	3.4	8.7	11.2	2.56	3.29
Indianapolis E.					
	34.4	58.0	59.5	1.69	1.73
Anderson W.					
	1.2	4.2	4.6	3.50	3.84
Anderson E.					
	16.3	28.5	29.9	1.75	1.83
Muncie W.					
	1.3	3.6	4.4	2.77	3.38
Muncie					
TOTAL TRIP	56.5	103.0	109.6	1.82	1.94
TOTAL URBAN	5.9	16.5	20.2	2.80	3.60
TOTAL INTERURBAN	50.6	86.5	89.4	1.71	1.77

TABLE XI.
PERSONAL FACTOR OF MOTORMEN.
LOCAL RUNS.

Name.	East. Total K.W.H.			West. Total K.W.H.			Trips.	
	Min.	Average	Max.	Min.	Average	Max.	East.	West.
Eller	122	135	148	114	125	136	6	6
Lee	116	121	126	124	129	130	4	4
Robbins	122	131	138	119	124	128	4	4
Green	113	123	131	126	134	141	3	3
Young	118	122	128	112	128	145	3	6
Griffin	124	130	140	127	131	134	3	4
Embry	108	126	154	134	135	185	3	2
		127			130		26	29

TABLE XI.—Continued.

LIMITED RUNS.

Name	Total K.W.H. Min.	Average.	Max.	Trips.
Motsie	101	109	115	13
Frazier	95	101	104	12
		105		25

TABLE XII.

LOCAL RUN OF CAR 237

Station.	EAST BOUND. Starts.	(A) K.W.H. Per Car Mile.	(B) Sq.Root Mean Sq. Cur.	*Ratio. B/A	Ratio C/D	WEST BOUND. (C) Sq. Root. Mean Sq. Cur.	(D) K.W.H. Per Car Mile.	Starts.
Indianapolis	12	3.27	49.6	21.9	14.6	49.5	3.39	12
Siding 27	5	2.83	53.1	18.8	....	....	....	6
Lawrence	3	2.63	53.1	20.2	....	....	1.48	1
Oaklandon	1	2.12	46 9	22.1	....	....	3.01	2
McCordsville	2	1.91	43.1	22.6	....	....	3.15	5
Fortville	2	2.49	51.1	20.5	23.9	34.7	1.45	1
Ingalls	3	2.39	49.2	20.6	20.1	44.0	2.19	5
Pendleton	5	2.29	49.0	21.4	21.9	47.2	2.16	5
Anderson	7	2.98	50.4	16.9	23.7	55.0	2.32	3
Chesterfield	1	1.50	36.1	24.0	22.4	57.0	2.53	2
Daleville	1	1.90	41.4	21.8	23.2	54.8	2.36	2
Yorktown	8	2.84	48.9	17.2	20.2	54.3	2.69	4
Muncie								
TOTAL TRIP	50	2.48	48.9	1[illegible].7	21.6	49.0	2.27	48

K.W.H. per ton mile 85.6 ..... 78.3
K.W.H. per trip 140.2 ..... 118.3

An allowance of 45 passengers is made per trip, at an estimated weight of 3.00 tons.
*The ratio B or A C D is the "running factor" which multiplied by the K.W.H. per car mile gives the square root of the mean square value of the current flowing in the motor armature. The square root of the mean square value of the running current is the value of the current to be used in a shop test.

car mile by the limited cars is 4.42 k.w.h. against 5.88 by the local cars. The best urban performance shown by the limited cars is 2.31 k.w.h. per car mile against 2.92 k.w.h by a local car. The best average urban consumption for the limited cars is 2.8 k.w.h. on east bound trips against 3.79 k.w.h. by the local cars. In general, therefore, at all points, the limited cars show better handling, more uniform records, and records which are much lower than the average of the local car performance. Occasionally, however, as is pointed out, a car in local service will show a better record over a short distance than will the limited cars.

The comparison of limited east and west bound trains given in Table X. shows little difference between them. The consumption of the west bound trains is uniformly slightly higher than that of the east bound. This is a distinct characteristic of the traffic over this system, as has already been pointed out.

Another interesting phase on this subject is brought out by the results which are given in Table XI. Here we have the work of the different motormen given in terms of the minimum, average and maximum energy consumption of the cars in their charge during the three days of the general test. The best trip going east shows an energy consumption of 108 k.w.h., which is 43 per cent. less than the highest car consumption, recorded 154 k.w.h. It is interesting to note that these minimum and maximum records were made by the same man, the average of his three trips, however, is 126 k.w.h., which differs but by one per cent. from the average of all of his east bound trips. These results more than any others, bring out the fact that the variations in the energy consumption in local service are chiefly due to conditions existing at the time of specific runs. The average of the first man going east is 8 per cent. higher than his average going west. The average of the second man going east is 6.5 per cent. less than his average going west. The third man shows the greater consumption on his east bound trips; the fourth man the greatest on his west bound trips, and, so on for the others. Apparently, a motorman who so operates his car as to produce a greater energy consumption on his eastern trips than on his western, does so consistently, possibly, through some personal idea as to the way in which his car should be conducted over different portions of the road. For instance, the first man's minimum, average and maximum is less on his western trips than on his eastern; in the same way the work of the second man shows that on his eastern trips his minimum, average and maxi-

mum were consistently less than the minimum, average and maximum on his western trips. This condition holds true for five out of the seven men reported as operating local cars. On the west bound trips Young made his minimum trip with 112 k.w.h., which is the least of all, and his maximum trip was 145 k.w.h., which is the highest of all. Here again we have the same man making the best and the worst record, due in this case, probably as in others to local conditions existing at the time. From observation of the way in which different motormen handled their cars, it seemed that where indicating instruments were mounted on a car, the general energy consumption of the car improved. The ammeters, voltmeters and recording wattmeters had not long been placed in the cabs of the different cars before the motormen began to study the behavior of their cars with different conditions of starting, and rivalry sprang up among them which was very gratifying to notice, each man trying to make his runs with the least amount of energy consumption and the least maximum current indicated by his ammeter. For this reason it is believed that the results which are here reported show a performance over this system quite up to, if not better, than the usual performance, owing to the fact that the men were so quick to take advantage of the new conditions. The test on the first day of the general series, April 17th, has been presented here for the reason that the men were less accustomed to the instruments and therefore working more nearly under their usual habit. They were given no instructions whatever for the handling of their cars and any change which they may have made in operating them was entirely due to their own ideas in the premises. In the case of the limited runs results are given for but two men; however, they are sufficiently great in number to indicate quite accurately the character of their performance. Frasier produced results with a less consumption of power than did Motsie, his maximum and minimum being nearer his average than in the case of Motsie. This would seem to indicate that whereas in the case of any one man, conditions existing at the time of a run to a great extent modify the power consumption of the car, nevertheless, a given man may be able to operate his car under the same conditions as some other man with a less energy consumption. These differences can be more readily detected in the case of the limited runs than in the case of the local runs, for the reason that variables other than those of the personality of the motorman are to a greater extent

eliminated; the stops are less frequent, the speeds more uniform and conditions altogether less subject to change during different runs.

Special Car Tests.

The special car tests were undertaken with the special object in view of ascertaining as to how nearly the car equipments were being worked up to their rated capacity, inasmuch as the heating of a motor, performing a given character of work, has all to do with its capacity for accomplishing a greater or lesser amount of this work. The first point to be considered in connection with such tests is the arranging of adequate means for accurately determining the cycle of current fluctuations and the temperatures of the windings and cores. In street railway service motors are subjected to more variable conditions than are ordinarily to be found in industrial plants, and, consequently it is very much more difficult to predict the exact effect upon the motor of operating it for propelling a car over a given road than it is to predict the capacity of a motor for the handling of a certain load in stationary practice.

To equip a car to make the necessary instrumental observations is no small task. In the case of the present tests, the desired result was accomplished only after the experimentors had experienced considerable trouble and overcome many obstacles.

In all, three cars were tested, numbers 237, 252 and 255. Car number 237 has a total weight of 51,650 pounds, 38,150 pounds being in the car body, trucks, etc., and 13,500 pounds being in the electrical equipment; all of this weight came directly on the driving wheels. As these cars are always operated in the same direction and have, therefore, the controlling apparatus stationed at the forward end, this end weighed 650 pounds more than the rear end. The motors of this equipment were geared in the ratio of 30:52; the car wheels having a diameter of 32½ inches. The car, as equipped, has a length of about 40 feet. This type of car is used by the Union Traction Company chiefly on its northern lines between Anderson, Marion and Elwood.

Car number 252 is of a type more common on this system and has, in fact, already been described in part. It is 52 feet 6 inches long. Its weight is 63,100 pounds, of which 50,300 pounds is in the car body, motor truck, etc., and 12,800 in the electrical equipment. Of this weight 40,300 pounds was carried on the driving wheels. The motors were geared with a ratio of 20:51; the wheels being 34½ inches in diameter.

Car number 255 is similar to car number 252 except that the ratio of the gearing has been changed from 20:51 to 23:48. The object of this change in the gearing was to determine the effect upon the motors of working them up to a higher capacity and in improving the schedule of operation of the cars.

In conducting the tests, each of the cars was in turn equipped with a Thompson indicating wattmeter placed in the main circuit to indicate the power consumption. A specially calibrated Thompson wattmeter was in addition arranged to indicate the power lost in the field of one of the motors. The object of so arranging this instrument was to enable a determination to be made of the square root of the mean square value of the current. In the case of each of the motors this instrument was adjusted to meet the special requirements.

For ascertaining the speed of the car a small magneto generator was used belted to the car axle in connection with a calibrated voltmeter. In addition, definite determinations were also made of the instantaneous value of the current, of the line voltage and of the voltage at the terminals of one of the motors. Readings were taken continuously during any one trip, the trips extending from Indianapolis to Muncie going east and from Muncie to Indianapolis going west.

The cars were kept in the usual service of the road and an effort made to prevent the tests from interfering in any way with the normal operation of the cars. During times of acceleration or retardation, records were made at intervals of about five seconds, but at times of uniform speed the intervals between readings were made of a longer duration, from fifteen to twenty seconds.

Temperature measurements were made both by the increase in resistance method and with thermometers. The temperature measurements, however, were successful only to the extent of determining the effect of the degree of average work to which the motors were subjected.

In discussing the tests no attempt will be made to review the results in detail further than is necessary to bring out certain points which are deemed of interest in connection with the performances of cars.

As of the motors tested those of cars 252 and 255 are most important, their characteristics are given in Fig. 7. These motors are of the type No. 50 C, rated at 150 h.p.

The running logs of cars 252 and 237, which were tested in the

spring of 1902, are given in Figs. 10, 11 and 12, and also in Tables numbered from 12 to 18. Table 12 is a summary of the results of a test made upon car 237 in local service. From this data it will be noted that columns A and D give the k.w.h. per car mile, and contain values which do not differ materially from the averages of Tables V. and VI. The east bound run shows an average consumption per car mile of 2.48 k.w.h. and the west bound run an average of 2.27.

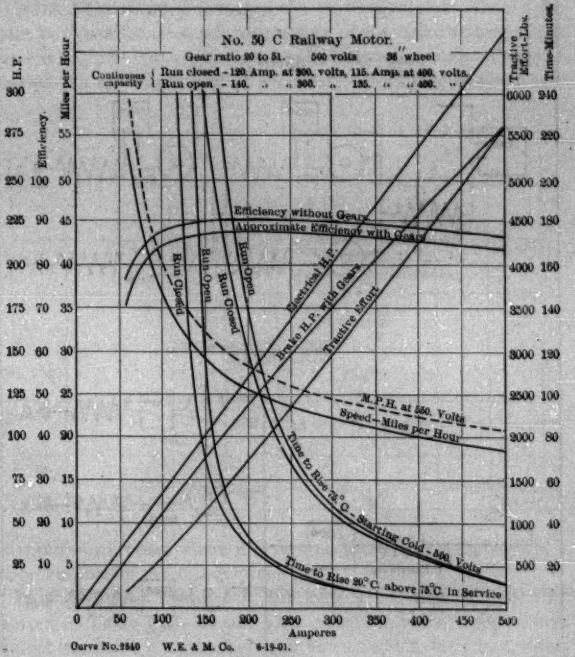

No. 50 C Railway Motor.
Gear ratio 20 to 51. 500 volts 36" wheel
Continuous capacity { Run closed - 120. Amp. at 300. volts, 115. Amps. at 400. volts.
Run open - 140. " " 300. " 135. " " 400. "
H.P.
Efficiency.
Miles per Hour
Tractive Effort-Lbs.
Time-Minutes.
Efficiency without Gears
Approximate Efficiency with Gears
Run Closed
Run Open
Run Open
Run Closed
Electrical H.P.
Brake H.P. with Gears
Tractive Effort
M.P.H. at 550. Volts
Speed--Miles per Hour
Time to Rise 75° C. - Starting Cold - 500. Volts
Time to Rise 20° C. above 75° C. in Service
Amperes
Curve No. 2340 W. E. & M. Co. 6-19-01.

FIG. 7.

In columns B and C are given the determinations of the square root of the mean square value of the current in the motors between stations and for the total trip. The column headed " ratio of B/A " gives the ratios of the data in column B to that in column A. In the same way the column headed " ratio C/D " gives the ratios of the values in column C to the values in column

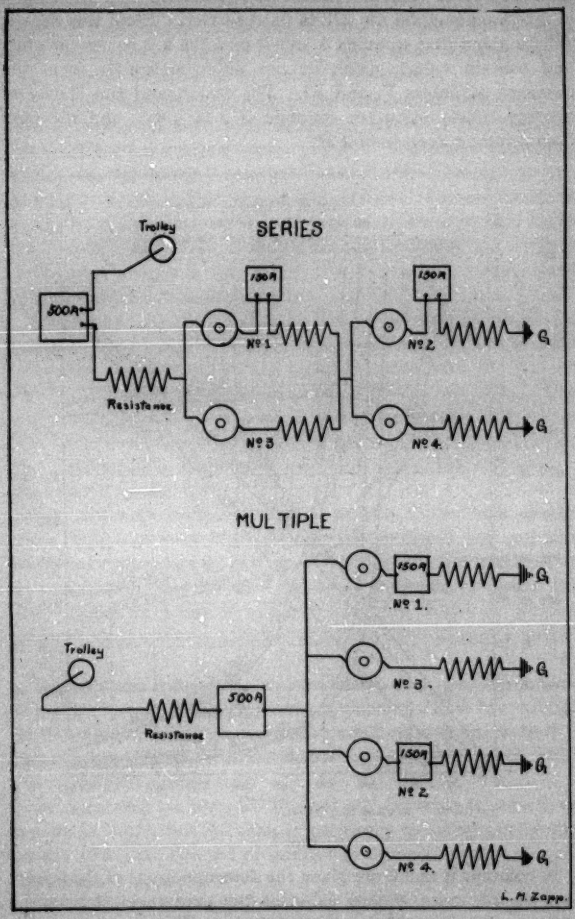
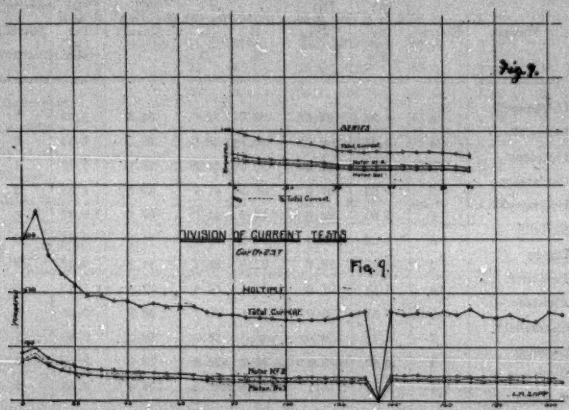


FIG. 8.—Motor Diagram, Car No. 237.

D. That is, these columns give the ratio of the square root of the mean square current to the k.w.h. per car mile. These ratios give an indication of the proportional heating effect of the power delivered from the feeders under the variable conditions of operation.

For present purposes, since the weights of the cars are known, the ratio taken between the square root of the mean square current and the car mile consumption gives an estimate of what may be termed the running factor of the car equipment. Should the ratio be taken between the square root of the mean square of the current and the k.w.h. per motor mile, the value obtained may be termed the running factor of a motor. The latter value is best



adapted to purposes where it is desired to make comparisons of a large number of motor equipments.

In the present instance it will be noticed that the running factors of Table XII. do not vary greatly in value; they remain almost constant for runs between towns which may be considered as presenting anything like similar conditions of operation.

In Table XIII. we have a similar accumulation of data for a complete round trip made by car 252. Here the ratios are much more variable than are those in Table XII. This is due to the fact that on this particular run car 252 was subjected to a very unusual schedule, as in all 62 stops were made. The ratios of the west bound run are much more constant than

TABLE XIII

LOCAL RUN OF CAR 252.

Station.	EAST BOUND. Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Root Mean Sq. Cur.	Ratio. B / A	WEST BOUND. Ratio. C / D	(C) Sq. Root Mean Sq. Cur.	(D) K.W.H Per Car Mile.	Starts
Indianapolis ..	8	4.20	97.5	23.2	33.0	85.5	2.59	7
Siding 27.....	8	3.45	106.0	30.7	38.0	89.0	2.34	3
Lawrence	5	3.32	107.2	32.3	39.6	78.0	1.97	1
Oaklandon . .	2	2.63	97.9	37.2	41.7	82.5	1.98	3
McCordsville...	3	6.30	95.0	15 0	41.0	97.0	2.37	4
Fortville	3	1.72	98.4	57.2	36 2	91.9	2.54	2
Ingalls	2	5.78	124.0	21.5	36.7	81.8	2.32	2
Pendleton	14	5.17	109.0	21.1	34.4	87.5	2.55	8
Anderson.....	6	3.52	98.9	28.1	46.7	95.8	2.05	4
Chesterfield...	2	2.74	128.0	46.7	36.9	86.0	2.33	1
Daleville	3	2.82	73.9	26.2	36.7	78.9	2.15	3
Yorktown	6	2.94	116.1	39.5	32.4	105.4	3.25	6
Muncie.....								
TOTAL TRIP ..	62	3.12	98.4	31.5	37.8	92.1	2.44	44

K.W.H. per ton mile, 89.5 ..... 67.0
K.W.H. per trips, 176.2 ..... 133.0

An allowance of 45 passengers is made per trip, at an estimated weight of 3.00 tons.

TABLE XIV.
LIMITED RUN OF CAR NO. 237.

Station	EAST BOUND. Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Root Mean Sq. Cur.	Ratio B/A	WEST BOUND. Ratio C/D	(C) Sq. Root Mean Sq. Cur.	(D) K.W.H. Per Car Mile.	Starts.
Indianapolis	10	2.86	49.5	17.3	19.7	46.9	2.38	6
Siding 27	2	2.19	78.2	35.7	25.1	44.2	1.76	1
Lawrence	0	1.66	37.8	22.8	25.9	31.6	1.22	
Oaklandon	0	1.61	35.5	22.0				0
McCordsville	1	1.34	41.0	30.6	18.4	45.7	2.48	1
Fortville	0	1.89	40.8	21.6	21.5	38.3	1.78	1
Ingalls	0	1.41	38.4	27.2	20.4	44.0	2 16	0
Pendleton	1	1.92	45.6	23.8	23.9	45.0	1.88	3
Anderson	4	2.25	80.3	35.7	24.6	51.0	2.09	0
Chesterfield	0	1.92	45.9	23.9	20.7	41.1	1.99	0
Daleville	1	1.87	48.3	25.8	23.9	41.9	1.75	1
Yorktown	1	2.23	50.5	22.6	2.23	53.5	2.40	3
Muncie								
TOTAL TRIP	20	2.02	46.0	23.6	22.8	44.4	1.95	16
K.W.H. per ton mile		69.8					67.5	
K.W.H. per trip,		114.2					110.2	

An allowance of 30 passengers is made per trip, at an estimated weight of 2.25 tons

TABLE XV.
LIMITED RUN OF CAR 252.

Station.	EAST BOUND. Starts.	(A) K.W.H. Per Car Mile.	(B) Sq. Rt. Mean Sq. Cur.	Ratio. B/A	WEST BOUND. Ratio. C/D	(C) Sq. Rt. Mean Sq. Cur.	(D) K.W.H. Per Car Mile.	Starts.
Indianapolis	10	3.14	102.2	32.6	30.0	84.1	2.80	4
Siding 27					39.7	72.6	1.83	2
Siding 15	5	2.23	83.5	37.5	35.3	86.2	2.44	4
Anderson	3	2.37	88.1	37.6	36.4	78.9	2.17	2
Muncie								
TOTAL TRIP	18	2.32	87.2	37.6	36.2	78.0	2.10	12
K.W.H. per ton mile,		67.5					60.3	
K.W.H. per trip,		131.2					118.8	

An allowance of 30 passengers is made per trip, at an estimated weight of 2.25 tons.

TABLE XVI.

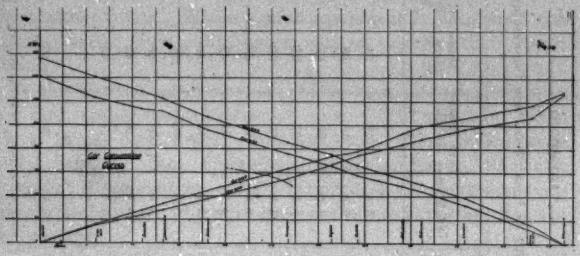
PERFORMANCE OF MOTORS ON CAR NO. 237 ON LOCAL TRIP FROM INDIANAPOLIS TO MUNCIE, MARCH 28, 1902.

	Time in Min.	Starts.	Dist. Miles	Ave. Speed M.P.H.	Max. Speed M.P.H.	K.W.H. Per Car Mile. A	Sq. rt. Min. Sq. Cur. (B.)	Ratio $\frac{B}{A}$	Max. Cur.	Min. Volts on line
Indianapolis										
	20	12	3.4	10	23	2.27	50	22	260	345
Siding 27										
	20	5	7.4	22	38	2.83	53	19	335	405
Lawrence										
	10	3	4.5	27	37	2.63	53	20	300	440
Oaklandon										
	5	1	2.1	25	37	2 12	47	22	255	430
McCordsville										
	8	2	4.8	36	42	1.91	43	23	265	415
Fortville										
	7	2	2.8	24	40	2.49	51	21	275	475
Ingalls										
	12	3	4.7	23	42	3.39	49	21	320	390
Pendleton										
	23	5	8.7	23	39	2.29	49	21	370	380
Anderson										
	15	7	5.1	20	42	2.98	50	17	365	425
Chesterfield										
	5	1	2.0	24	36	1.50	36	24	255	525
Daleville										
	8	1	5.1	38	43	1.90	41	22	325	475
Yorktown										
	19	8	6.0	19	41	2.84	49	17	320	425
Muncie										
Indianapolis										
	152	50	56.6	22	42	2.48	49	20	370	345
Muncie										

those for the east bound run. During this part of the trip conditions more nearly approximating the normal existed.

In Table XIV we have data bearing upon a complete round trip made by car 237 in limited service. The chief differences to be noted here by comparison with the data given in Table XII are that owing to the more uniform conditions of operation the ratios or running factors are very uniform indeed, departing in general only to a slight degree from the total trip running factors given at the bottom of the table.

Table XV. is a statement of the results obtained on a limited run upon car 252. Here it is seen that the ratios or running factors are also comparatively constant, except where the car is operated within the limits of Indianapolis. Here the ratios are reduced somewhat; this is common in all similar urban runs.



For the purpose of presenting the data more clearly an expanded statement of it is made in Table XVI. for the western bound trip of car 237, mentioned in connection with Table XII. Here the time between points, starts between points, distance between points, average speed maintained between points, maximum speed between points, k.w.h. per car mile, running factor, the square root of the mean square of the current, maximum current and minimum volts on the line between points, are recorded. On this trip car 237 attained to a maximum speed of 43 miles an hour running from Daleville to Yorktown. Between these two points but one start was made and an average speed of 38 m.p.h. was maintained. During this run therefore the maximum speed was but 13 per cent. in excess of the average speed. Again the data tells us that although the k.w.h. per car mile, 1.9, is low still, since the minimum voltage on the line is high, and the maximum current, 325 amperes, moderate, the conditions in general

TABLE XVII

PERFORMANCE OF MOTORS ON CAR NO. 252 ON LOCAL TRIP FROM INDIANAPOLIS TO MUNCIE, MARCH 24, 1902.

	Time in Min.	Starts.	Dist Miles	Ave. Speed M.P.H.	Max. Speed M.P.H.	K.W.H. Per Car Mile. (A)	Sq. rt. Min. Sq. Cur. (B)	Ratio $\frac{B}{A}$	Max. Cur.	Min. Volts on line.
Indianapolis	19	8	3.4	11	25	4.20	97	23	230	365
Siding 27	23	8	7.4	19	38	3.45	106	31	310	355
Lawrence	12	5	4.5	23	40	3.32	107	32	280	350
Oaklandon	5	2	2.1	25	36	2.63	98	37	250	320
McCordsville	10	3	4.8	29	38	6.30	95	15	240	400
Fortville	8	3	2.8	21	39	1.72	98	57	270	440
Ingalls	9	2	4.7	31	42	5.78	124	22	260	335
Pendleton	32	14	8.7	16	38	5.17	109	21	370	300
Anderson	14	6	5.1	22	52	3.52	99	28	390	410
Chesterfield	5	2	2.0	24	38	2.74	128	47	270	485
Daleville	11	3	5.1	28	43	2.82	74	26	270	360
Yorktown	21	6	6.0	17	40	2.94	116	40	285	380
Muncie										
Indianapolis	173	62	56.6	20	52	3.12	98	32	390	320
Muncie										

are favorable for an especially low square root of the mean square current. Accordingly, the running factor has a high value, 22.

On the run from Anderson to Chesterfield on the other hand, the k.w.h. per car mile is 2.98 for a like distance of 5.1 miles, seven stops were made and a maximum speed was attained of 42 m.p.h. However, the average speed was only 20 m.p.h. or less than one-half of the maximum speed. These conditions, therefore, have a tendency to unduly increase the square root of the mean square current value, which is brought up to 50. In this case, then, owing to the fact that the maximum current is higher and the minimum current lower than in the first case cited, and furthermore, owing to the fact that during periods of starting a good deal of power is absorbed in the starting resistance, the k.w.h. per car mile increases faster than the square root of the mean square current value, and consequently we get a very low value, 17, for the running factor. Where a good equipment is considered, the running factor gives a fairly good idea of the conditions which obtain.

In this test the maximum value of the running factor, 46, is 15 per cent. higher than the average value. The minimum value, 17, is 15 per cent. lower. Frequent stops, other things being equal, have the effect of lowering the running factor. It is also true that the maximum current attained and the average minimum voltage under which the cars operate are important items in modifying it.

In Table XVII. results are given similar to those recorded in Table XVI. for a run between Indianapolis and Muncie of car 252 on local service. The number of stops made by car 250 on this trip is high and on arriving at Muncie it was 23 minutes overdue. The car consumption per car mile, 3.12 k.w.h., for this run is the highest obtained at any time during the tests and in itself shows the unfavorable conditions under which the car was operating. It was frequently required to lay over on sidings and in addition to make a great many intermediate stops. These unfavorable conditions are shown by the excessively high car consumption between McCordsville and Fortville, where a maximum consumption per car mile of 6.3 k.w.h. occurs. The average car consumption between these points, as shown by Table V., is but 2 k.w.h. per car mile. Again in running between Ingalls and Pendleton we have 5.8 k.w.h. per car mile, against an average value again of 2 k.w.h. per car mile in Table V. We also find that the average voltage at the motor terminals through

TABLE XVIII.

VARIATIONS IN LINE VOLTAGE BETWEEN STATIONS DURING EAST AND WEST TRIPS OF CAR No. 252.

Station.	Line Voltage Going East.			Line Voltage Going West.		
	Min	Ave.	Max.	Min.	Ave.	Max.
Indianapolis						
	365	456	590	335	418	460
Siding 27	355	446	585	310	442	580
Lawrence	350	475	580	350	453	540
Oaklandien	320		545	330	450	540
McCordsville	400	422	520	330	412	540
Portville	440	483	575	385	482	535
Ingalls	335	477	580	410	450	535
Pendleton	300	406	550	300	408	540
Anderson	410	495	570	335	403	560
Chesterfield	485	523	545	515	540	560
Daleville	360	491	560	350	493	575
Yorktown	380	457	565	475	496	555
Muncie						

TABLE XIX.

TEMPERATURE RISE OF MOTORS PER ROUND TRIP.

Number of Car.	Sq. Root Mean Sq. Current.	Temperature above Atmosphere, Degrees C.			
		Arm No. 1	Arm No. 2.	Field No. 1.	Field No. 2.
252	83	43.5	57.5	41.0	53.5
252	93	45.0	59.5	38.5	48.5
Average.	88	44.3	58.5	39.7	51.0
237	47	40.5	39.0	33.5	34.5
237	45	39.5	36.5	29.5	29.5
Average	46	40.0	37.7	31.5	32.0

out this run was quite low, the average minimum being 320 volts between Pendleton and Anderson.

It is not surprising therefore that the running factor varies considerably in these tests. The value for the trip is 32, which is low for this car equipment; normally it runs as high as 37. The lowest value of the running factor is 15 between McCordsville and Fortville. This is less than half of what it should be. The highest value is 57 between Fortville and Ingalls, which is 35 per cent. higher than it should be under normal working. The low value, 15, is due to the fact that the maximum speed is not much in excess of the average speed value, the maximum current values relatively low and both the minimum and average voltage values low, the former being 400 and the latter 422.

In the case of the run between Fortville and Ingalls the maximum speed attained is nearly twice the average speed and the voltage is high; also the average voltage and the maximum current values are high. Low voltage invariably has the effect of decreasing the running factor, whereas high voltage increases it. Notable examples may be taken for low values in the case of the run between McCordsville and Fortville and between Pendleton and Anderson. In these cases as shown in Table XVIII., the average voltage was respectively 422 volts and 406 volts. Examples of high values in the running factor occur between Fortville and Ingalls, 57, and between Chesterfield and Daleville, 47. In these cases the average voltages were respectively 483 and 523.

It is not meant, however, that the voltage should be taken as the only criterion for variations in the running factor. The number of starts, the maximum and average speeds and the current peaks also have much to do with it. In considering the records of the cars on these special tests it is not so much a matter of surprise that variations should occur in the running factor as that under the variable conditions of actual service the running factor should remain for the majority of the runs so nearly constant.

In Tables XIII. and XV. we see that during the east bound local run of car 252, although 44 stops were made, the running factor does not vary materially from the running factor given for the limited runs on this car both eastbound and westbound. Of course during the limited tests the conditions which obtained were fairly uniform and therefore uniformity in the values of the running factor should be expected. In the local runs this is not

the case. However, Table XIII. shows that with variations in the k.w.h. per car mile of from 2.54 to 2.15 or through a variation of 18 per cent., the running factor is practically the same.

A comparion of the values given in Tables XII. and XIV. show even better results than these. In these tables it will be found that numerous values of car consumption ranging from 1.61 k.w.h. per car mile to 3.27 k.w.h. per car mile can be picked out, giving a running factor of 22. This is a variation in power consumption per car mile of over 100 per cent.

In making definite suggestions with reference to the ratio, which for want of a better term has been called a "*running factor*," it is not meant to bring it forward as more than a means of getting some mental conception of what the conditions were which obtained during the special limited and local tests. When a large amount of data is accumulated, it is frequently a matter of some difficulty to so arrange it as to admit of intelligent comparisons being drawn between different sets of results and anything which enables one to obtain a mental grasp of the situation is to be welcomed.

That the running factor should in most cases be fairly constant under variable conditions of operation may be explained as follows. At times when a car is starting the $I^2 r$ losses in the windings are large, owing to the high starting current, and the core losses low, owing to the low speed. Therefore during the starting periods the $I^2 r$ losses dominate among the variable quantities in the measure of the total losses occurring in the motor. When a car has attained speed and uniform conditions of running have been reached, for instance on a level stretch of track, since the current values decrease, the $I^2 r$ losses fall to a normal value and the iron losses rise to a normal value at the same time. When operating under constant voltage the electrical energy delivered to the motors from the line is proportional to the current, but during the starting periods and when the high points of the $I^2 r$ losses are most important, the least amount of electrical energy supplied is being effectively utilized by the motors on account of the starting resistances and the fact that the motors are working at a point of low efficiency. Consequently, a temporary increase in the $I^2 r$ losses means also a temporary increase in the power supplied to the motors per unit of distance traversed, and we have, in a crude way, the variations in the power supplied per car mile following the variations in the heating value of the current.

Since the wattmeter connected in the field circuit gives the square root of the mean square of the current values and the wattmeter connected in the power circuit registers a value in excess of the average power delivered to the motors, it follows (curiously enough) that the ratios of the two wattmeter readings taken under widely different conditions, in different cases, are practically constant. It is an interesting fact if not a valuable one.

In comparing the running factors of the two cars on the basis of k.w.h. per motor mile, instead of per car mile, it must be remembered that car number 252 is equipped with two motors which operate in parallel under normal conditions; whereas car number 237 is equipped with four motors operating in parallel under normal conditions. The running factor values given in connection with car 237 are therefore only one-fourth as large as they should be, and those given in connection with car number 252 only, half as large as they should be for comparison on a k.w.h. per motor mile basis. That it is fair to assume an equal division of the current between the motors of the equipment of car 237 is shown by the curves shown in Fig. 9. The data for these curves were obtained during a special run to determine the division of current between the motors of this equipment Although the division is not quite exact, yet it is sufficiently so for present purposes.

Following through the calculation, we find that the average running factor per motor mile of the motors of the equipment of car 237 is 86.0 and the average running factor of the motors of car 252, 74.4. From this we would expect that for a given schedule the motors of car 237 will heat up more than will the motors of car 252 under the same conditions of service. This, however, is not the case, as is shown in Table XIX., which gives the temperature rise of the motors on both cars after single round trips between Muncie and Indianapolis.

From Table XIX. it is seen that the armatures of the equipment of car 252 run about 14° hotter than do the armatures of car 237 and that the fields of the motors of car 252 run about 15° hotter than do those of car 237. This difference is more than likely due to the fact that the smaller motors have greater radiating surface per unit of power developed. In fact, the common condition in motor design is that less trouble is experienced in supplying sufficient radiating surface for smaller motors than in supplying the proper radiating surface for large motors.

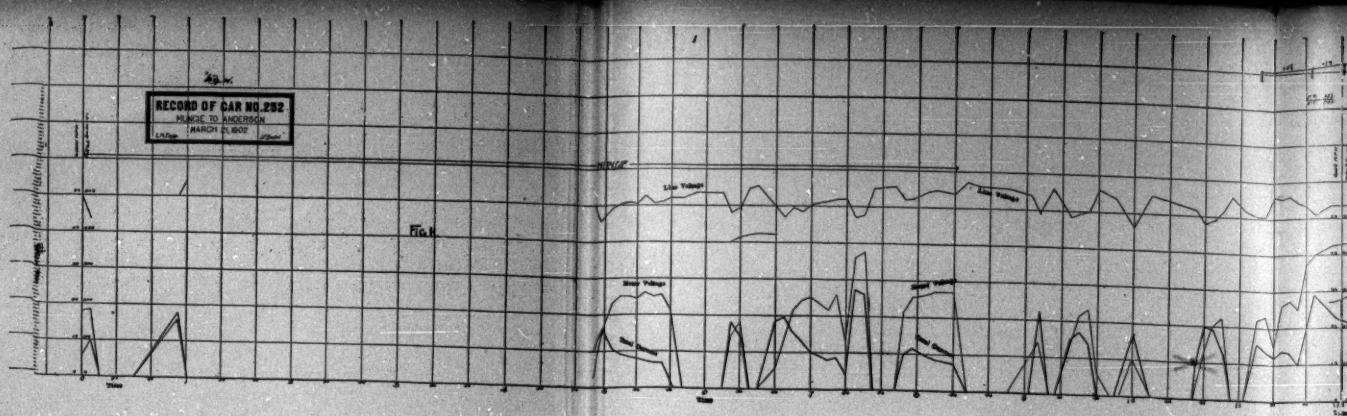
It is interesting to notice that of the motors on car 252, since No. 1 motor receives most of the breeze caused by the motion of the car, it being the one nearest the front, temperature of motor No. 1 is lower than of motor No. 2. In fact it has the advantage of motor No. 2 by about 12°.

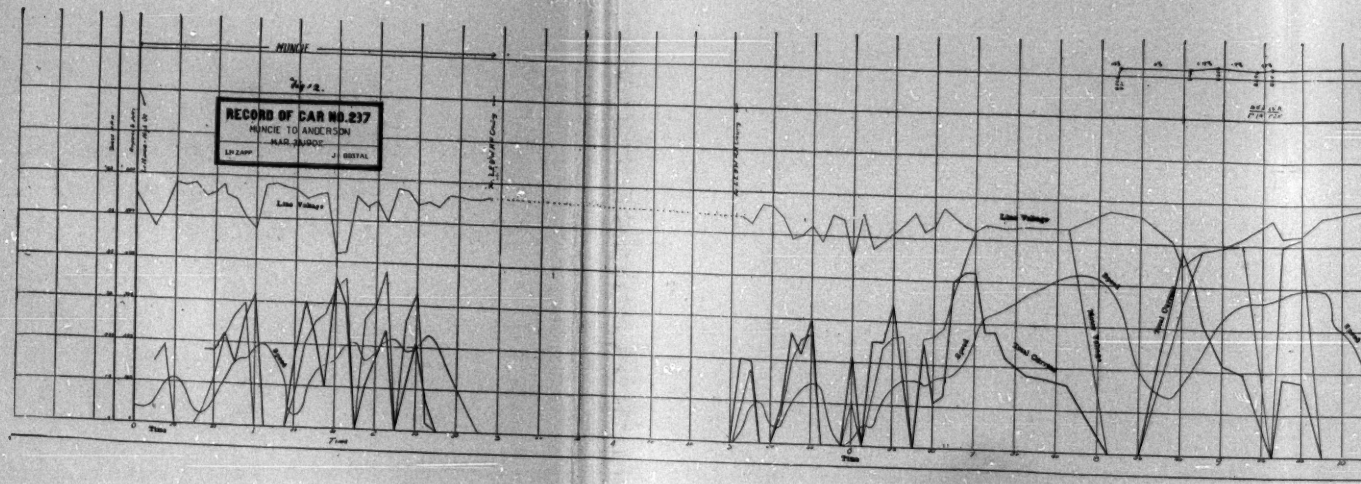
In the matter of economic operation, car 252 shows a higher economy than does car 237. On the local trips car 237 consumed from 78 to 83 k.w.h. per ton mile, the starts per trip being 48 and 50 for the two runs repectively. Car 252 during its local trips showed a car consumption of 67 and 89 k.w.h. per ton mile, the starts being 44 and 62 per trip respectively. Comparing the trips, in which the number of starts are the same, car 252 shows up the best. In the limited trips the same result is apparent. As shown in Tables XIV. and XV., car 237 took an average of 68.6 k.w.h. per ton mile with an average of 18 stops for the two trips, whereas car 252 consumed an average of 63.9 k.w.h. per ton mile. The average number of stops of the latter car was 15.

The differences here brought out are not great and a more extended test of the two cars would probably show that in general operation they have much the same power consumption.

In Fig. 10 curves are given to illustrate the rate of power consumption of cars 252 and 237 on local runs between Indianapolis and Muncie. No particulars that are especially worthy of note are developed by these curves except that car 252 shows a more uniform car consumption than does car 237 on both trips. When the cars were bound east car 252 consumed the greatest amount of power whereas on the western trips car 237 shows a greater power consumption.

Inasmuch as the special tests made on cars 237 and 252 developed the fact that the limit of adhesion had not been approached in any of the tests; one of the equipments (car 255) of the type used on car 252 was furnished with a new set of gears making the gear ratio 23:48 instead of 20:50. The conditions under which car 255 was operated makes it difficult to compare its performance with that of either the limited or local runs made by the regular cars. The record of the tests of car number 255 discussed here was taken during a complete round trip. The instruments and observers were arranged in substantially the same manner as for the other special tests and the results of the test over the distance from Muncie to Anderson are plotted in Fig. 13. In Figs. 11 and 12 curves are given for local tests on cars 252 and 237 over the same distance. These curves make the relative per-


RECORD OF CAR NO.232
MUNCIE TO ANDERSON
MARCH 21,1902
MUNCIE
Line Voltage
Time


MUNCIE
RECORD OF CAR NO.237
MUNCIE TO ANDERSON
MAR 21,1902
Line Voltage
Time

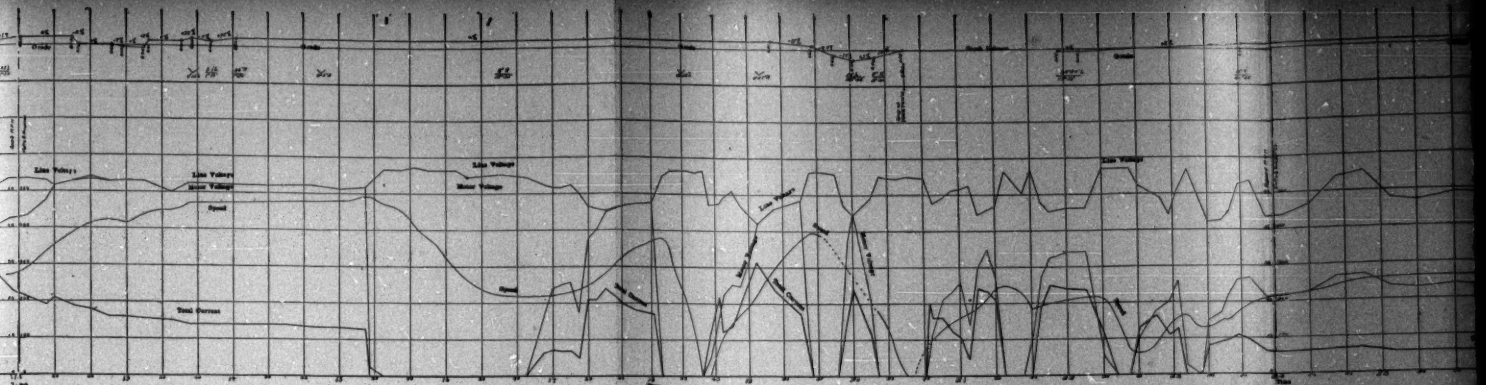


FIG. 11.—(Car Tests.

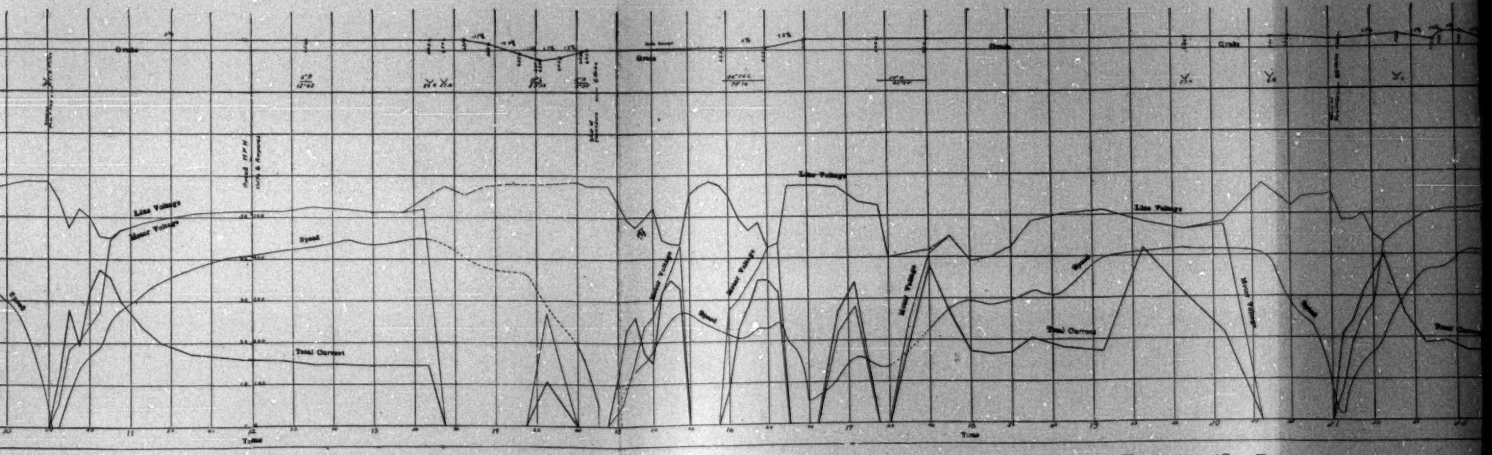


FIG. 12.—(Car Tests.

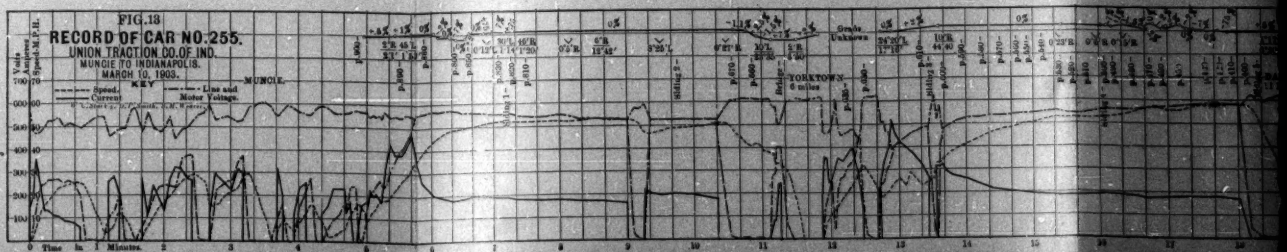


FIG. 13.—(Car Tests.

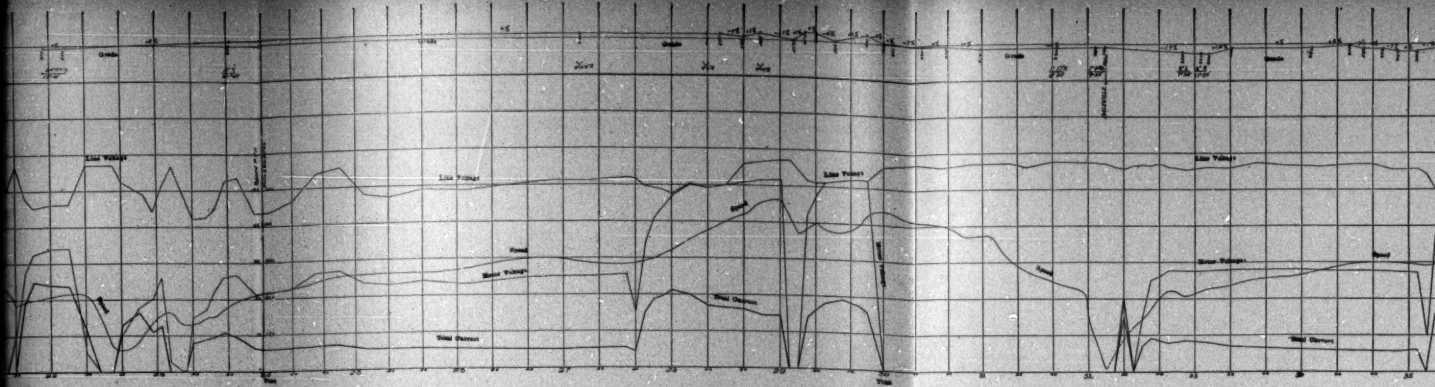


FIG. 11.—(Car Tests.

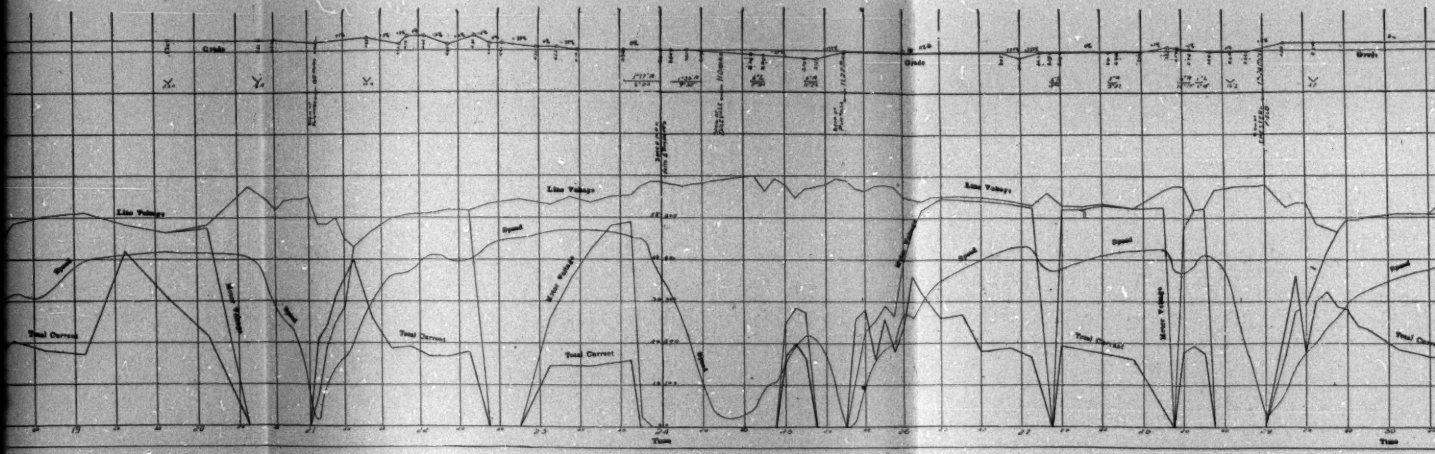


FIG. 12.—(Car Tests.

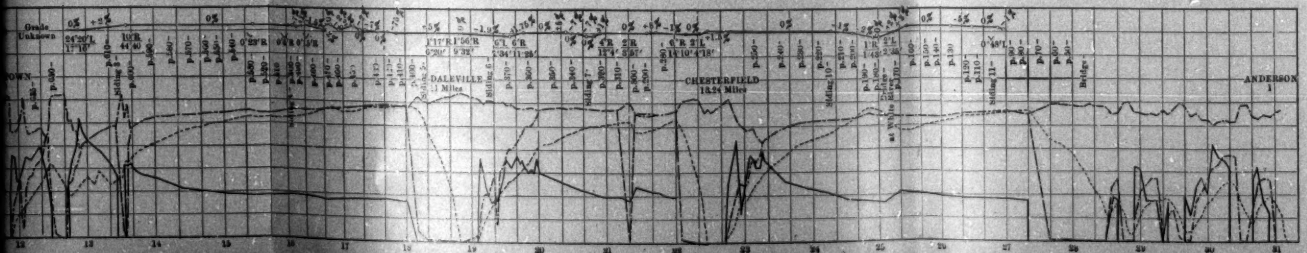
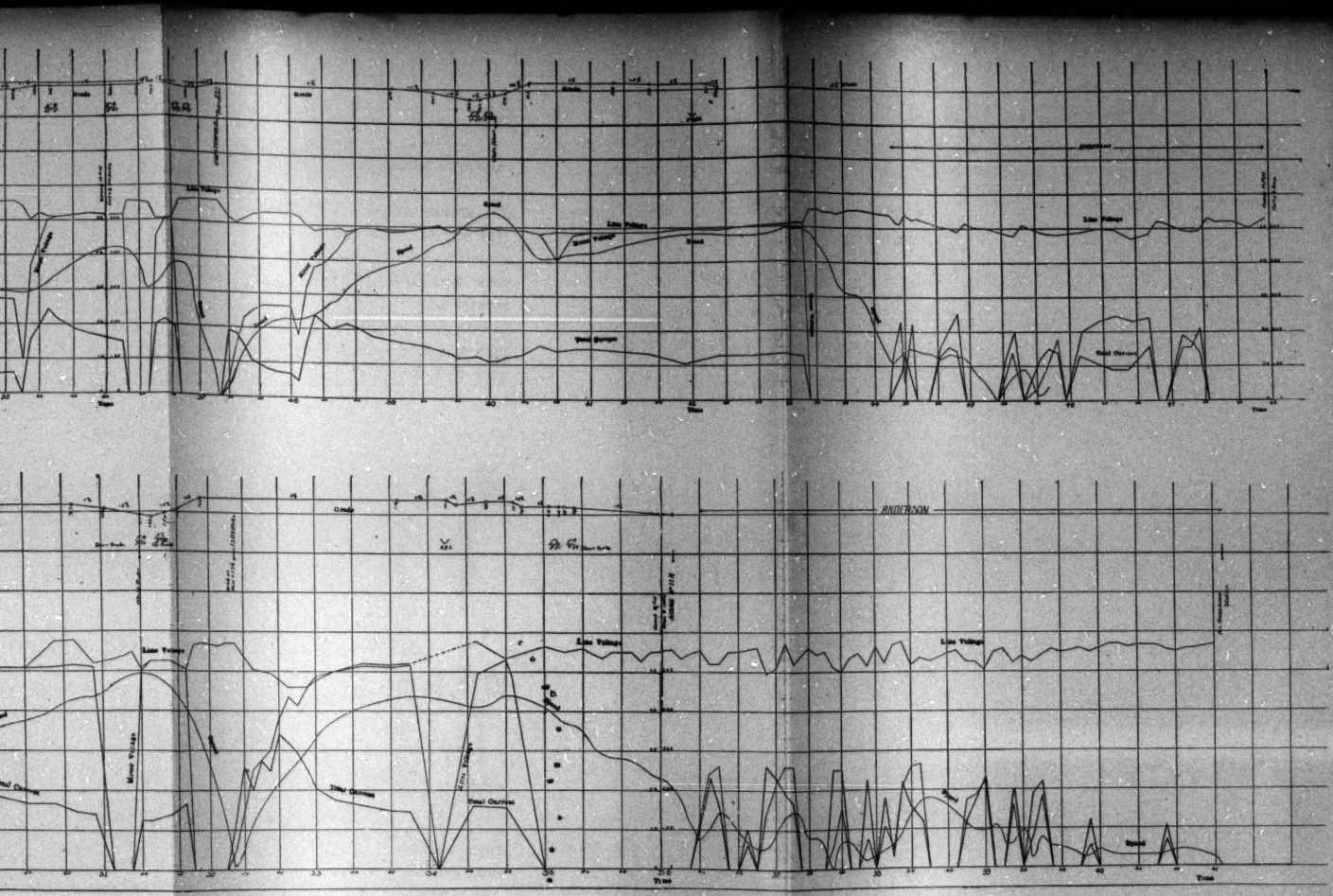


FIG. 13.—(Car Tests.


ANDERSON

formance of the different cars apparent without undue explanation.

Under the ordinary conditions of local service starts are made about once in every one and one-half miles. In the test trip of car number 255, starts were only made at the principal towns along the route. In comparing therefore this test with the special tests of car number 252 we find that in local service car number 252 made less starts than did car number 255, and in limited service made more. A resumé of the performance of cars 255 and 252 is given in Table XX. From this table it is very

TABLE XX.

COMPARISON OF CAR TESTS.

Number of car	255	252	252
Service, west bound	semi limited	local	limited
Weight	63,100	63,100	63,100
Gear ratios	23:48	20:51	20:51
Total time trip, min.	122	156	126
Time urban work, min	44	40	34
Time interurban work, min.	78	116	92
Average speed for trip, m.p.h.	28	22	27
Average urban speed, m.p.h.	8	9	10
Average interurban speed, m.p.h.	39	26	33
Total starts	18	44	12
Urban starts	5	15	7
Interurban starts	13	29	5
Maximum speed, m.p.h.	64	52	
Running speeds	50–55	40–45	40–45
Running currents	173	145	145
Train resistance corresponding lbs. per ton	27.7	19.9	19.9
Time to reach 25 m.p.h.	30	30	30
Acceleration current, max. series	280–340	200–300	200–300
Acceleration current, max. par	320–540	250–300	250–300
Consumption, k.w.h., p.c.m., west	2.20	2.44	2.10
Consumption, k.w.h., p.c.m., east	2.38	2.80	2.32
Sq. root mean sq. current, west	95.6	92.1	78.0
Sq. root mean sq. current, east	105.5	98.4	87.2
Running factors, west	43.5	37.8	36.2
Running factors, east	43.3	31.5	37.6
Average voltage, west	485	429	
Total consumption k.w.h., west	124.9	138.0	118.8
Total consumption k.w.h., east	134.3	176.2	131.2

evident that the change in the ratio of the gears produces a car capable of very much more efficient operation, in that its consumption per car mile is about the same as that of car number 252, whereas the speeds attained and maintained by the car are very much in excess of the local and limited service performance of car number 252. In this special run car number 255 maintained an average speed of 28 m.p.h. between the stations in Muncie and Indianapolis. Car number 252 maintained an average speed of 22 m.p.h. in the local service and an average speed of 27 m.p.h. in limited service between the stations in Muncie and Indianapolis. If the time during which the cars are passing through Muncie, Indianapolis and Anderson is deducted, we find that the average

speed maintained by car number 255 during the interurban run is 39 m.p.h., making 13 interurban starts. In the local interurban run of car number 252 an average speed of 26 m.p.h. was maintained, making 29 starts; and in the limited run of car number 252, an average speed of 33 m.p.h. was maintained with only five starts. Car number 255, therefore, excels the performance of car number 252, although car 252 was running under better schedule conditions in view of the less number of starts made by it. In fact, in spite of the greater number of starts car number 255 made the interurban run outside of the cities in 78 minutes, whereas it took car number 252 in the limited service 92 minutes to make the run and in local service, 116 minutes to make the run. Since the square root of mean square of the current does not differ greatly from that shown by car number 252, the temperature of the motors working under the new conditions is not carried above a good allowable working value. The increased economy developed by this car is nothing short of remarkable, and it brings out very strongly the value that will accrue to any system in which careful adjustments are made of the car equipments to the work which they have to perform.

The earning capacity of the car in view of its ability to make the greater number of trips a day with the same crew is greatly increased by this change in the gearing and it is altogether a better machine as gauged by engineering and economic standards.

The running factor of car number 255, figured on the car mile basis, is 48 for the westbound trip and 40 for the eastbound trip. Calculated on the basis of the motor mile basis, the average running factor for car 255 is 86.8. Comparing this running factor with those for cars 252 and 237, it is quite evident that the change in gearing has markedly influenced the running factor of the motors raising it from 74.4 up to that of car 237, *i.e.*, 86.0. This is due to the fact that we have here a higher current consumption for a shorter time, thereby getting a higher square root of mean square value with approximately the same power consumption, per motor mile, since under ordinary circumstances the voltage is approximately constant.

In comparing the train resistance of these cars, we find that when car number 255 is running at uniform speeds of from 50 to 59 m.p.h., showing an average of 55 m.p.h. at 554 volts and 143 amperes, the train resistance amounts to 27.9 pounds per ton. In the case of the tests of car number 252, the car main-

tained speeds of from 40 to 45 m.p.h., with a current consumption of about 145 amperes. This corresponds to a train resistance of about 19.9 pounds per ton.

The acceleration of the cars over this system does not differ very much from that common to steam roads. Cars 255 and 252 required from 30 to 31 seconds to attain a speed of 25 m.p.h. and very frequently a longer time than this was required, especially by car number 252. The rate of acceleration developed during the tests varied in general from about .4 to .9 m.p.h. per second. A maximum acceleration as high as 1.0 was attained occasionally on down grades, the minimum acceleration being about .25 m.p.h.p.s.

The train records given in Figs. 12 and 13 are chiefly of interest in bringing out the fact that on this particular system low rates of acceleration exist largely through necessity. Where power is transmitted at 500 volts over considerable distances, an enormous expenditure in copper is necessary if high rates of acceleration are to be maintained at starting by cars remote from the substation. With the feeder distribution system of the Union Traction Company, a heavy current demand has the effect of so reducing the voltage at the cars as practically to limit the maximum obtainable rate of acceleration.

Comparing Fig. 13 with Figs. 11 and 12, the apparent ease with which car 255 attains to speeds running up close to 60 m.p.h. is quite remarkable. The average running speed of car number 252 being but little above 40 m.p.h.

Appendix.

It would be an unwarranted omission should this series of papers on the tests of the Union Traction Company, of Indiana, be closed without acknowledgement being made to the students of Purdue University who bore the burden and brunt of making the records during the three days of the general test.

In order to give these young engineers as varied experience as possible, a schedule was arranged whereby the men working in eight-hour shifts, eight hours on and eight hours off, would not have the same work to perform during any two working periods. Accordingly, a man who was on duty in the Anderson generating station during the first shift, might be in the Marion substation during the second shift, and, on an Indianapolis-Muncie division car during the third shift. The men were required to move from one station to the next during their relief

time, and, also, to get their meals as well as sleep during this time. Frequently they had to sleep on cots in the substations, and, at times, on floors. Occasionally, owing to some disarrangement of the car service, a man was delayed in reaching his next post of duty and the observer whom he was to relieve had to work from 12 to 14 hours at a stretch. The men went through this trying ordeal without loosing records at any point and without a man having failed to report for duty at the scheduled time, except for causes beyond his control. The roll of the men who did this work and did it well, is as follows:

Seniors in Electrical Engineering Having Charge of Parts of the Tests.

J. P. DINSMORE, F. B. HOFFT, D. H. WILSON,
J. F. DOSTAL, C. HOLLINGSWORTH, L. M. ZAPP,
W. B. GREGG, R. A. PETICOLAS, O. C. STEIN,
C. E. REID.

Seniors in Electrical Engineering.

C. E. ADAMS, J. C. HUFFMAN, A. E. WOOD,
E. D. FRISTOE, N. F. ROBERTS, J. W. DEITZ.
B. M. MERRILL, F. B. WILKERSON,

Seniors in Mechanical Engineering.

E. DAVIS, J. S. TATMAN, C. B. VEAL.
T. W. NEWBURN, E. N. DASHIELL,

Seniors in Civil Engineering.

L. W. DINSMORE,
W. H. LANE.

Juniors in Electrical Engineering.

JUDSON BOUGHTON, W. M. HOEN, D. R. WATERS,
W. C. BRITTEN, C. P. JOY, H. WEAVER,
B. C. CONSTABLE, F. W. JUDSON, R. M. BRET,
I. B. CORNS, J. R. MCCONNELL, F. S. DENEEN,
C. O. DALE, J. K. OSTRANDER, W. THORN.
R. C. DIETZ, W. T. SMALL,
I. HICKMAN, O. P. SMITH,
J. B. HILL, W. C. STARKEY,

Juniors in Mechanical Engineering.

T. M. ANDREW, A. R. KELLEY, R. E. CLISBY,
H. D. HARTLEY, J. H. PHLOEN,

Sophomores in Electrical Engineering.

R. W. HARRIS,
A. W. JOHNSON.

Sophomores in Mechanical Engineering.

I. E. ARTZ, A. F. BERGER, C. R. MISNER.

Discussion of "Interurban Car Tests," Communicated by E. P. Roberts and I. H. Sherwood.

Car Tests on Northern Texas Traction Company.

Numerous tests were made by Mr. Bret Harter of the interurban cars which were of three types, namely: (1) Standard interurban passenger car, (2) Larger and special parlor car, and (3) package freight car, with and without trailer; and comparisons are given of the results obtained under different conditions of operation.

A description of the various cars and their equipment is as follows:

Car.	No. 1 & No. 7.	Sagamore.	No. 12.	No. 9.
Type	Standard closed Interurban Passenger.	Interurban Parlor Car.	Standard Interurban Express.	15-Bench Open Interurban Trailer.
Make	Kuhlman.	Kuhlman.	Kuhlman.	Kuhlman.
Length over all	44′ 5″	59′ 6″	40′ 0″	45′ 8″
Width	8′ 4″	8′ 5″	8′ 4″	8′ 0″
Total Weight in Tons, Car and Equipment	25.4	31.0	20	17.4
Number Motors	4	4		
Make	Westinghouse.	Westinghouse.	Westinghouse.	....
Mfg. No.	56	76	56	
Gear Ratio	32-50	24-58	24-58	
Controllers	K 14	L 4	K 14	
No. of Trucks	2	2	2	2
Make	McGuire.	Brill.	McGuire.	McGuire.
Mfg. No.	35	27	35	40
Dia. of Wheels	33″	33″	33″	30″
Wheel Base	6′	6′	6′	4′ 2″
Make Brake	Christensen.	Christensen.	Christensen.	Christensen.
Type "	Direct Acting Storage Air.	Independent Direct Acting Air.	Independent Quick Acting Automatic Air.	Quick acting Automatic Air.

The dates of the test and weather conditions, etc., were as follows:

Date, 1902	9/16	9/17	9/17	8/19	9/22	9/24	11/14
Car	1	1	1	Sagamore.	12	12 and 9	7
Trip	1	1	1	1	1 and 2	1	1 and 2
Direction	E & W	E & W	E & W	E & W	E & W	E & W	E & W
Weather	Clear.	Cloudy (Rain Dallas end.)	Clear.	Clear.	Rain.	Clear.	Clear.
Temperature	90°	85°	85°	Warm.		Cool.	Cool.
Rail	Dry and clean.	Dry and clean except Dallas.	Dry and clean. Dallas end wet clean.	Dry and clean.	Wet and clean. Cities slippery.	Dry and clean.	Dry and clean.

In Ft. Worth, the interurban cars make a run of approximately 1.8 miles where high speed cannot be made; the terminus being at the court house.

In Dallas there is a distance of 4.1 miles of city track where slow speeds are required, and this is down grade, averaging possibly 1 per cent. Dallas is approximately 200 ft., lower than Ft. Worth.

Detailed Log of Run.

The following is an example of a portion of a log and is presented merely to indicate the general character of the observations made.

Time.	Place.	Track.	Position Controller.	Miles per hr.	Amp.	Volts.	Watt hr. Readings	Remarks.
12:32	26.5	S.S. 1	0		0	600	4299600	Coast to
37	24	0%	S		60	575		24
	23.5		S	35	50	575		
38.5	23	0.14% +	S	25	70	570		
	22.3	1.3 % +	S	25	80	525		
41	22	0.17% +	S	28	60	535		
		0.15% +	S	28	50	500		
42.75	21	0.7 % +	S		50	485		
		0.7 % +	S		75	600		
	20.5	0.07% +	0		0	625		Coast to 20.1
44.5	G.P.	0.07% +	0	0	0	610	4305000	Stop
45	G.P.	0.07% +	S		80	530		
46	20	0.4 % +	S		80	530		
	19.9	1.0 % −	P					
	19.3	1.6 % +	P	40	175	450		
48	19	0.6 % −	0	0	0	630		Met a regular.
49	19		P		250			
50.5	18.5	0.2 % +	P	35	190	440		

See Tables I, II, III, IV.

Comparing Tables No. 1 and No. 2 it will be noted that the k.w. hours per car mile is greater for the entire run than for the high-speed portion only, and this is due to the greater number of stops in the towns and running on resistance. The average k.w. is less for the entire run than for the high-speed portion and this is due to the slower speed in towns, running on series.

The following illustrates this point:

T. & P. Crossing to Oak Cliff, Interurban Run.

Car	No. 1*.	Sagamore.	No 12.	12 & 9	No. 7	No. 7.
Rate of run in M.P.H.	29.3	29.3	27.3	22.3	23.5	27.5
K.W. hrs. per Mile	2.03	2.07	1.76	2.73	1.91	1.66
Watt-hrs. per ton Mile.	75.0	62.7	81.7	64.5	78.5	64.8
Average K.W.	59.4	61.	47.8	61.0	45.0	45.8

Ft. Worth to Dallas, Entire Run.

Car	No. 1†	Sagamore.	No. 12.	No. 12†	12 & 9	No. 7.	No. 7.
K.W. Hrs. per Mile	2.16	2.15	1.88	1.81	2.81	1.94	1.76
Watt Hrs. per ton Mile.	79.7	65.2	87.2	82.2	66.2	75.7	68.7
Average K.W.	48.1	52.7	37.7	42.1	56.4	35.6	36.5

* No. 1. Average of run of 9/17 Tables 1 and 2.
†12 – 12 & 9, Average of run. Ft. Worth to Siding 29.

Comparison of Results of Tests of Car No. 1.

Test of September 16th was with motors in parallel as much as possible, including hill climbing. Obtained high speed but more energy per car mile as compared with subsequent tests made September 17th, when the controller was handled more efficiently, and the car allowed to coast, though the speed was not quite as high.

Car No. 7.

Practically the same as No. 1.

The object of the two trips was to note a comparison of the effect of stops. The first trip having a considerable number and the second comparatively few, the result in k.w. per car mile is materially in favor of the second, especially on the west bound trips, where the time of the run is almost the same, but the stops almost three times as many. See Table I.

Also note Table II., which shows the effect of stops on the high speed run, where the result is very marked. Also note Tables III. and IV. Comparing No. 1 and No. 7 and the first test of September 17 of No. 1 and of November 14th of No. 7, there being about the same number of stops, shows that car No. 1 took more k.w. per car mile but the schedule speed was higher, whether the difference is entirely on this account we are not prepared to state, as there were many other circumstances which might affect the results, such as condition of the track, motorman, etc.

Private Car "Sagamore."

It will be noted that the "Sagamore" makes practically the same schedule speed as the regular passenger cars, but it could not do this and make as many stops as the passenger cars are capable of making, for the reason that it is not geared for the same high running speed. Gearing for slower speed tends to efficiency of operation, but whether the materially better results obtained for the "Sagamore" in watt-hours per ton mile was entirely due to the gearing, is at least questionable It will be noted that the k.w. hours per miles was about the same as for Car No. 1 for tests made on the 17th (and comparisons should not be made with tests made on the 16th because of special conditions of such tests). It should be noted, however, that car No 7 gave better results in this respect than No. 1, and lower actual figures than the "Sagamore," but the watt-hours per ton mile were lower for the "Sagamore" than for No. 1, or even for No. 7, on test of same with the fewest number of stops.

Car No. 12.

Car No. 12 is a slightly lighter car than No. 1, and has the same motors as No. 1, and the same gearing as the "Sagamore." The k.w. hours per mile for the total run shown on Table I. was high, and with reference to Table IV., it will be noted that this was especially due to the run in Oak Cliff and Dallas. This car not only has frequent stops, but, owing to the character of the business, namely, taking up and discharging freight, it shifted back and forth at the sidings, etc., so that the results should not be compared on the same basis as obtained by other cars.

TABLE I.

This gives the data obtained from the entire run of interurban cars, including runs in Ft. Worth and Dallas.

Place	Ft. Worth to Dallas.													to Siding.		No. 29 to Dallas.			
Date, 1902	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30												
Wt. of Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt.	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.5	35.1	34.4	34.6	30.5	30.4	30.4	30.3	34.5	34.35	34.35	34.35
Time	82.0	95.5	89.0	96.0	90.0	96.0	88.5	97.5	99.5	109.5	102.5	121.0	74.7	82.0	88.5	93.0	113.5	113.5	91.85	108.5
Miles per Hr	25.1	21.6	23.1	21.4	22.8	21.4	23.2	21.2	20.8	19.2	20.1	17.1	24.4	22.2	20.6	19.6	18.2	18.1	22.4	19.0
K.W. Hrs.	84.6	86.4	70.2	73.2	75.6	77.4	72.0	75.6	58.2	72.6	88.8	98.4	52.4	57.6	82.2	88.8	64.2	69.6	59.1	62.1
K.W. Hrs. per Mile	2.46	2.52	2.04	2.13	2.2	2.26	2.1	2.2	1.69	2.07	2.58	2.84	1.72	1.9	2.7	2.93	1.86	2.03	1.72	1.81
Watt. Hrs. per Ton Mile	91.0	92.5	76.0	81.5	80.5	80.6	64.0	66.5	82.5	92.0	61.0	66.5	80.0	84.5	63.5	69.0	72.5	78.9	67.0	70.4
Average K.W.	61.8	54.3	47.3	45.8	50.4	48.4	58.8	46.6	35.5	39.9	52.0	48.8	42.0	42.2	55.6	57.3	33.9	36.7	38.6	34.4
Stops			25	27			24	24	19	14	15*	13*	13	9	8	8	29	30	15	11

*No. 9 Trailer dropped and picked up at Siding 29, Oak Cliff, City Limits.

TABLE II.

This gives the results obtained on the high speed portion of the road, being strictly the interurban section.

Place	T. & P. Crossing to Oak Cliff City Limits.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt. in Tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.6	28.5	28.6	28.5	28.6	28.45	28.45	28.45
Time	53.2	58.5	59.5	57.5	58.5	57.25	56.5	60.0	62.25	63.5	72.75	81.0	72.75	73.0	59.5	65.0
Miles per Hr.	32.0	29.1	28.6	29.6	29.1	29.8	30.2	28.4	27.6	26.9	23.6	21.1	23.6	23.4	28.7	26.3
K.W. Hrs	72.0		57.6	54.0	61.8	57.0	61.2	57.0	49.2	51.0	76.2	79.8	55.8	53.4	48.3	46.5
K.W. Hrs. per Mile	2.54		2.03	1.9	2.18	2.01	2.15	2.0	1.74	1.79	2.66	2.80	1.95	1.87	1.70	1.63
Watt Hrs. per Ton Mile	94.0		75.5	72.5	80.0	72.0	65.5	60.0	84.0	79.5	63.0	66.0	78.9	78.0	66.1	63.6
Av. K.W.	81.3		58.1	56.4	63.4	59.7	65.0	57.0	47.4	48.2	63.0	59.1	46.1	43.8	48.7	42.9
Stops			9	8			9	9	7	5	5	5	21	21	4	6

TABLE III.

This gives the results obtained in Ft. Worth.

Place	Ft. Worth Terminal to T. & P. Crossing.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt. in Tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Time	13.3	11.5	13.0	14.5	15.0	14.25	16.5	13.5	12.5	18.5	15.75	12.0	12.75	17.0	14.25	12.5
Miles per Hr	8.1	9.4	8.3	7.45	7.2	7.6	6.55	8.0	8.64	5.8	6.9	9.0	8.47	6.35	7.58	8.66
K.W. Hrs.	7.2		6.6	9.0	7.2	9.6	6.8	9.0	3.6	6.6	6.0	9 0	3.9	6.3	4.8	6.3
K.W. Hrs. per Mile	4.0		3.66	5.0	4.0	5.34	3.78	5.0	2.0	3.66	3.33	5.0	2.16	3.5	2.66	3.5
Watt Hrs. per Ton Mile	148.0		136.0	191.0	146.0	190.0	115.0	150.0	97.5	162.0	78.5	117.0	84.3	136.0	104.0	136.0
Av. K. W.	32.4		30.4	37.2	28.8	40.4	24.7	40.0	17.3	21.4	22.8	45.0	18.3	22.2	20.2	30.3
Stops			10	14			10	10	6	4	3	3	4	3	5	1

TABLE IV.

This gives the results obtained in Oak Cliff and Dallas.

Place	Oak Cliff City Limits to Dallas Terminal.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	9/14	9/14	9/14	9/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. of Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt. in Tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.8	4.0	4.3	4.1	4.1	4.1	4.1
Time	15.5	25.5	16.5	24.0	16.5	24.5	15.5	24.0	14.75	27.5	14.0	28.0	18.0	23.5	18.1	31.0
Miles per Hr	15.9	9.65	14.9	10.2	14.9	10.0	15.9	10.2	16.7	10.5	17.1	9.2	13.6	10.5	13.6	7.94
K.W. Hrs	5.4	10.8	6.0	10.2	6.6	10.8	4.2	9.6	5.4	15.0	6.4	9.6	4.5	9.9	6.0	9.3
K.W. Hrs. per Mile	1.31	2.64	1.46	2.49	1.49	2.64	1.02	2.34	1.32	3.13	1.6	2.23	1.1	2.42	1.46	2.27
Watt Hrs. per Ton Mile	48.5	97.0	54.5	95.0	44.5	94.5	31.0	71.0	64.0	139.0	37.8	52.5	42.7	94.0	57.0	88.3
Av. K.W.	20.9	25.4	21.8	25.5	22.2	26.4	16.2	24.0	22.0	32.3	27.4	20.6	15.0	25.3	19.9	18.0
Stops			6	5			5	5	6	5	7	5	4	6	6	4

NOTE:—It should be noted that the results in Table No. 4 are included in those given in Table No. 1, and also that, at the time of the tests, the Oak Cliff Line was in poor condition as to track, bonding and overhead work. This was an old line, which has since been rebuilt.

The effect of adding a trailer on the k.w. hours per mile and the watt hours per ton mile is very marked, both on the entire run as given by Table I. and for the portions of the run as given by Tables II., III. and IV. the reduction in watt-hours per ton mile being very considerable.

In connection with the above it should be noted that the average k.w. for the entire run (see Table I.) for the regular passenger cars is less than 50 k.w. (omit test of September 16th, which was intentionally made under uneconomical conditions). Therefore, if the average efficiency of the motors was 75 per cent., the average output of the motors was slightly less than one-quarter of their rating, and it should also be noted that this does not include time for lay-over, which gives opportunity for cooling. Each motor is rated at 55 h.p.

[COMMUNICATED AFTER ADJOURNMENT BY MR. A. H. ARMSTRONG]

In commenting upon the very admirable paper brought out by Messrs. Goldsborough and Fansler, one point strikes me as rather inconsistent, and that is the elaborate methods taken to secure and make use of the square root of the mean square current per motor. As the chief object of the tests seemed to be to obtain this value, it is interesting to note what use is made of it. To this end Mr. Goldsborough has constructed a new term which he calls the " running factor," this being the ratio of the square root of the mean square current per motor to the kilowatt hours per car mile. The term has no rational reason for existence, as obviously this " running factor " or ratio will vary widely, depending upon the kind of service and will in no way serve as an indication of whether the proper motors are used, whether the gearing is correct, etc. It is obvious that the kilowatt hour per car mile depend largely upon the gear ratio used, and the rate of acceleration chosen for a given schedule and frequency of stops. With the series-parallel controller, a service calling for much series running will considerably affect the kilowatt hours per car mile without in any way affecting the square root of the mean square current. For long runs there may be some similarity in the values obtained for this " running factor," but the results cannot be used in any comparative sense, have no direct bearing upon the fitness of the equipment for the work, and not in any way indicate the heating of the motors. The term seems to me to complicate an otherwise rather simple problem without in any way furnishing additional accuracy. The use of the " running factor " term ignores the possible efficiency of acceleration of the motors. This efficiency of acceleration is the ratio of work done by the motors to the energy input of the car or train, and will vary from 40 per cent. to as high as 75 per cent. or 80 per cent. on the longer runs. The square root of the mean square current is not at all affected by the efficiency of acceleration of the motors, and hence any conclusions drawn from the ratio of square root of the mean square current to the kilowatts per car mile input

must necessarily show considerable variation, due to the variable efficiency of acceleration of different lengths of runs.

Mr. Goldsborough noted a considerable variation in energy consumption on the shorter runs. I believe this was largely due to the fact that the method of taking ampere time curves was not well adapted to very short runs when the accelerating current forms the greater part of the total ampere input. Some time ago at Schenectady we were met with this same difficulty and some of our engineers advised a recording voltmeter and ammeter which gave the current reading at every instant, thus eliminating the personal element of the observer and giving much more accurate results than can be obtained with either two second or five second readings.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

SOME RECOMMENDATIONS CONCERNING ELECTRICAL AND MECHANICAL SPECIFICATIONS OF TROLLEY INSULATORS.

BY SAMUEL SHELDON AND JOHN D. KEILEY.

INTRODUCTION.

At present there appears to be no standard basis for comparison of the relative merits of insulators which are supplied for use in ordinary overhead trolley line construction. It is obviously desirable that there should be a definite basis upon which a proper selection can be made.

With a view to formulating specifications of such materials, it was found necessary, on account of the lack of published data on the subject, to conduct a series of tests to determine the electrical and mechanical properties of these materials. The tests were made upon samples obtained in the open market from the stocks of well-known manufacturers. Some of the results of these tests are given below and recommendations concerning specifications of certain types are appended.

Determinations were made of the tensile strength of the samples, of the voltage necessary to perforate the insulation or produce an arc between conducting parts, of the mechanical softening temperature, and of the relative magnitudes of the insulation resistances.

TENSILE STRENGTH.

These tests were made in the usual manner, the samples being pulled apart by means of a Riehle 30,000 lb. universal machine. U-shaped pieces of round steel were passed through the metal eyes of such samples as globe, Brooklyn strain, and terminal strain insulators, and were clamped in the jaws of the machine.

The insulated bolts were passed through a properly sized hole in a steel plate. The threaded end was connected with a steel eyebolt by means of a steel threaded sleeve, and the tension was exerted between the eyebolt and the plate. The results obtained from breaking the samples are given below, the product of different manufacturers being represented by the letters *A*, *B*. *C* and *D*. The numerals represent the tension in pounds at the time of break.

$2\frac{1}{2}''$ Globes.

A	*B*	*C*	*D*
3710	5950	7725	6320
4510	5770	7475	6890

3″ Globes.

A	*B*	*C*
4210	11190	5450
5310	8930	5550

Small Brooklyns.

A	*C*	*D*
9990	10320	5520
11130	9010	6450

Large Brooklyns.

A	*B*	*C*
11490	19670	18510
10510	17140	18250

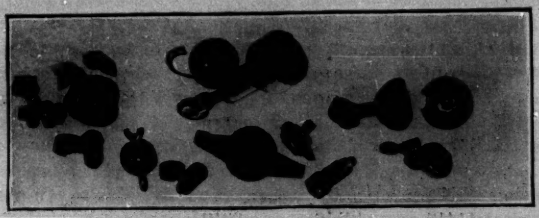
Insulated Bolts.

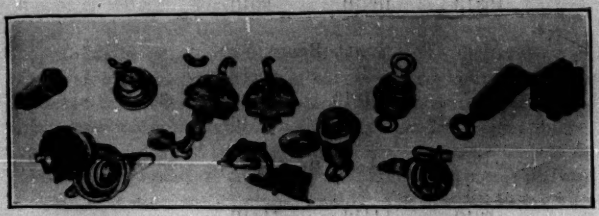
A	*B*	*C*	*D*
6370	6130	7360	3280
4495	5490	9010	2925

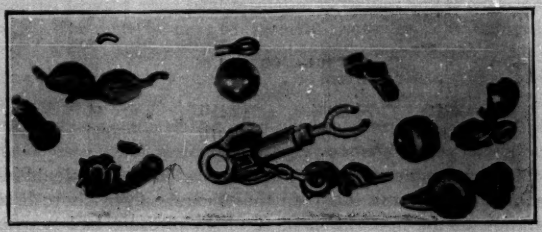
Some of the broken samples are shown in the accompanying illustrations. It will be noted that while some samples gave way in the eyes, others broke in the insulation. It is very desirable that strain insulators should be so designed that when subjected to a test for tensile strength, they should give way in the eyes. As these insulators are subjected to an uncertain strain while being installed and after being in use, it is of great importance that one may be able to depend upon the fact that, if the eyes be intact, the insulation is also in good condition.

Breakdown Voltage.

In carrying out these tests, the two metal portions or conductors of the insulators were connected respectively with the two high pressure terminals of a 1:200 step-up transformer, whose low-pressure terminals were connected in series with a regulating rheostat to a supply of alternating current at a fre-







Figs. 1, 2 and 3.

quency of 60. A dead-beat voltmeter was connected to the low pressure terminals. By manipulating the rheostat any desired voltage could be impressed upon the low pressure coil and its value could be determined from the voltmeter. The high pressure voltage would be 200 times as large provided the

secondary was unloaded; that is provided the insulator were unpunctured and there were no arcing present. The test was started with a low impressed voltage which was gradually raised until a sudden drop in the voltmeter reading indicated that a breakdown had occurred. The maximum reading multiplied by 200 is the breakdown voltage. The following results were obtained.

2½" Globes.

A	B	C	D
8010	8610	5610	7500
	7610	5110	6110
		4510*	5910

3" Globes.

A	B	C
11410	12810	8010
10810	10810	9010

Small Brooklyns.

	B	C	D
	14810	6710	35000
		5510*	

Large Brooklyns.

A	B	C
8010	14410	11410
4210	13010*	7610*
4010*		

Insulated Bolts.

A	B	C	D
12010	14450	12210	arc at
13010	14450	10010	25000

The voltage necessary to rupture the dielectric would undoubtedly have been less than the amounts given above if the duration of the application of the high pressure had been increased. In practice, trolley insulators are seldom subjected to a voltage greater than that of the generators or converters. Occasionally, however, they are subjected to moderately high voltages of short duration which arise from the disappearance of magnetic flux that has been created by short circuits. The values given above which are followed by an asterisk were obtained from tests

on insulators which were, at the time, under a tensile strain of about 4500 lbs. The dielectric strength is slightly reduced by strain, but in all the samples tested it was sufficiently high to meet the requirements of present practice

Heat Tests.

Oftentimes when a trolley wire breaks it becomes heated on account of the grounding of a broken end. Sometimes the insulating material in the round top hangers softens under the influence of the heat communicated from the wire and allows the ear and suspended wire to drop to the ground. Efforts were made to determine the temperature of the insulation at the time of softening. A hanger was screwed into a regular ear, and was suspended in an inverted position in a double-walled oven. A wire was attached to the suspended cap and was passed through a hole in the bottom of the oven. To this wire was attached a weight of 100 lbs. This weight is equal to that of about 200 feet of No. 000 copper trolley wire and it is quite possible that a hanger might be subjected to this strain. The temperature of the oven was raised by means of burning an arc lamp which was enclosed in it. As the temperature rose to a certain point, the insulating material softened and the suspended weight pulled the round top cap of the hanger away from its bolt. This temperature was noted on a mercury thermometer whose bulb was placed near the ear. Unquestionably, the temperature varies very much at different points inside the insulating material, such material being a good heat insulator as well as an electrical insulator. The material next to the metal, however, is probably the hottest and the tempertaure is nearly that of the metal. It is at this point that it softens most. The results obtained from three samples were, *A* 168° C.; *B* 168° C.; and *C* 145° C.

Appreciating the uncertainty of such a test, another method was devised which tested the hangers under working conditions. This method gives but relative results. Under the circumstances they are more to be desired than absolute values of temperature.

A soft iron round rod, $\frac{1}{4}''$ in diameter and 20″ long was clamped by an ordinary trolley ear, whose ends had been cut off so as to leave a length of $5\frac{1}{2}''$. This was suspended (Fig. 4), by means of a wire stirrup underneath a beam. Into the ear was screwed the bolt of the round top hanger to be tested. To the cap of the hanger was suspended a weight of 200 pounds. A current of 200 amperes was then sent through the iron. The time which

elapsed between closing the circuit and the separation of the parts of the hanger under the influence of the weight was noted. These times in minutes were as follows:

A	*B*	*C*	*D*
50	34	94	74

Two similar samples from the same manufacturer were tested, one with the cap underneath, as above described, and the other with the ear beneath. The times between the closing of the circuit and the breaking down of the insulators were respectively 31 and 33 minutes. This indicates that the position in regard to vertical arrangement during test is immaterial.

Efforts were made to determine roughly the character and the composition of the insulating materials employed by each manufacturer. Upon ignition, by applying a lighted match, each of the insulating materials burned quietly with a very small flame. There was some smoke and in all cases the characteristic odor of

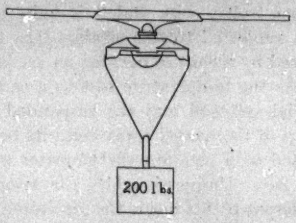


FIG. 4.

burning shellac. Each sample when placed in alcohol went partially into solution, leaving a residue. Mica and asbestos were present in some of the residues.

If the binding material be, in all cases, shellac, it is evident that the softening temperature is an indeterminate quantity. Shellac is somewhat viscous at ordinary temperatures, and its viscosity rises rapidly with increase of temperature. Insulating bolts, one from each manufacturer, were placed in boiling water and were allowed to remain until they had assumed the temperature of the water, *i.e.*, 100° C. In each case the insulating material had softened so as to permit of moulding under slight pressure. The viscosity, at a given temperature, is also dependent upon the relative amount of shellac to the other material present. This amount is liable to variation in samples of the same type from the same manufacturer.

Insulation Resistance.

The resistance of an ordinary strain insulator is very large, and, if it were not for the large number of them which are connected in parallel on a trolley system, no consideration need be given to this point. It is difficult to determine rapidly the individual resistances in ohms, hence the following method of determining the relative resistance values was devised.

A Holz machine when run at a constant speed, owing to its practically infinite internal resistance, functionates as a constant current generator. For obtaining the comparative values of the resistances of the insulators, such a machine was used as a source of e.m.f., and an arrangement of apparatus as shown below was employed:

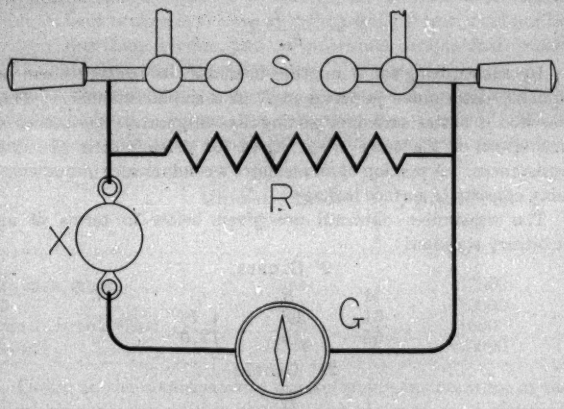


Fig. 5.

where S = spark gap of the Holz machine;
X = insulator under test;
G = a mirror galvanometer;
R = a resistance in which is included the leakage resistance of the Holz machine, and of the connecting wires.

By connecting together the two terminals of the insulator X, by means of a copper wire, practically all of the current I, which is produced by the machine, is made to pass through the galvanometer and it produces a deflection θ. Upon removing the copper wire, a current i_x will flow through the galvanometer, giving a deflection θ_x.

This deflection will be inversely proportional to the resistance of X. The rest of the constant current I will pass through R, which includes the leakage paths. Representing this current by i_R, there exists the following relations:

$$I = i + i_R$$

$$I - i_x = i_R$$

$$i_R R = i_x X = (I - i_x) R$$

$$\therefore X = \frac{I - i_x}{i_x} R$$

Since I and i_x are proportional to deflections θ and θ_x respectively,

$$X = \frac{\theta - \theta_x}{\theta_x} R$$

By substituting for X another insulator, its resistance can be quickly determined in terms of R in a similar manner. This method is better suited for getting the comparative resistances of insulators of the same shape, than for getting their absolute resistances. A portion of an insulator's conductance unquestionably consists of surface leakage.

The resistances obtained are given below in terms of an arbitrary standard:

2" Globes.

A	B	C
61	98	1.7
55	76	12.0

2½" Globes.

A	B	C
27	36	1
55	18	1.5
61	37	1

Small Brooklyns.

B	C
35	40
35	43

Large Brooklyns.

A	B	C
0.7	39	27
0.8	41	27

Specifications.

Specifications for the various forms of insulators used in trolley construction must vary with local conditions and with the policy of the user. Specifications for Globe and Brooklyn Strain insulators should cover the following points:

1. Dimensions.
2. Size of eye.
3. All samples tested shall break in the eye.
4. The average ultimate tensile strength of all samples subjected to mechanical test shall not be less than A lbs., and no individual sample shall show a tensile strength of less than 85 per cent. of the average tensile strength of all the samples that are tested.
5. The average break-down voltage, for samples which have been broken in the eye in the mechanical test, shall not be less than B volts, and no individual sample shall break down at less than 90 per cent. of B volts.

As to the values to be specified for ultimate tensile strength and breakdown voltage, the following are suggested, where high class insulators for use on 500 volt lines are to be specified.

	Ultimate Tensile Strength in lbs.	Breakdown Voltage.
2½ inch globes	6000	7000
3 " "	9000	10000
Small Brooklyns	9000	10000
Large "	18000	10000

Owing to the comparatively low softening temperature of the insulating materials generally used, and to the close proximity of the working conductor when in service, it is important that specifications for round-top hangers should impose a test for softening temperature. The following " hot rod test " is suggested:

Round-top hangers when suspended free from draught in an inverted position by means of a bronze ear weighing 8 ounces and being 5½ inches long, the ear clamping the middle of a round rod of soft iron ¼ inch in diameter and of at least 20 inches length between connectors, must be able, without breaking down or becoming permanently deformed by more than 1/16 inch, to sustain a weight of 200 pounds from the cap for one hour, a current of 200 amperes being passed continuously through the iron rod, the rod being cold at the start.

Discussion of Dr. Sheldon's Paper.

Mr. Joseph Sachs:—Moulded street railway insulators of the type that Dr. Sheldon describes are usually made of some loose inert insulating material mixed with a binding gum and compressed into shape. In many cases the formula would appear to pay little, if any, attention to the essential electrical characteristics of the ingredients, so long as the minimum gum and the maximum filler that would hold together were used. I most heartily second the recommendation Dr. Sheldon has made to standardize street railway insulator specifications. So far as some of his proposed requirements are concerned, however, I want to differ somewhat from him. In the first place, we may agree so far as the breaking of strain insulators is concerned in the elements exterior to the insulator. The mechanical strength of a strain insulator should be indicated by some exterior element. But there are other features to be considered mechanically, aside from the mere pulling. One of them is the knocking and vibration to which an insulator is subjected in regular service. Another and a very important factor in all insulators, is their stay-togetherness. I may say that nearly all moulded insulators to-day are bound together with shellac, or some gum or similar substitute. The insulating material in these insulators when softened under heat will permit the two strain parts, or the electrodes, we might say, of the insulator to pull apart, unless some mechanical provision, aside from the moulded insulation, is provided for holding them together. I believe that should be considered as an important element. In fact, all strain insulators or all trolley line insulators should be so constructed that under service strain conditions, if the moulded insulation should be ruptured, the two parts are still held by a mechanically stronger insulation.

I believe that the table for mechanical pulling strength on the ninth page is entirely too high. I can scarcely conceive of 18,000 pounds as being a necessary tensile strength for even a large Brooklyn strain insulator, although there may be special conditions where such may be the case. I know of very few strain insulators that stand in actual continuous service, with the rapping and knocking, even as much as eight or nine thousand pounds. These latter figures for first-class strain insulators of usual size should prove ample.

Now, again, the matter of melting point; the melting point of the moulded insulation used in nearly all trolley line insulators can be increased at the expense of its insulating properties. Such results can be obtained by using ingredients that give the compound a larger specific heat. These materials are mostly of a metallic oxide nature, and the insulation resistance and dielectric strength is usually brought down accordingly.

The iron bar heat test method described by the writers of the paper is good, but I believe it is carried a little too far. I think there are few practical conditions where enough heat would be generated in a trolley wire, and then only in case of a dead short

circuit from the trolley wire to the ground, which probably in many instances, or in most instances, would open up something on the line.

The puncture resisting strength of the insulator is, I believe, quite important, but I think too much stress is laid on the question of dielectric strength. An insulator for trolley use is mostly subjected to leakage conditions. On 500 volts it takes very little internal insulation to make the insulator stand up, but it takes a whole lot of surface and a whole lot of good material well put together to keep the insulator intact on the outside, not on the inside. Trolley line insulators are subjected to heating and cooling. The surface gets sticky and moist, accumulating dirt, and in a very short time of good, hard service we find more trouble arising from leakage conditions, due to cracks and other similar causes, surface leakage, and so on, than due to any actual puncturing of the interior; even though you might get inductive kicks due to short circuit suddenly being taken off the line.

I cannot see why, for trolley service of the same voltage, all insulators should not be subject to the same specifications so far as breakdown voltage is concerned. I do not see why a small insulator should be subjected to only 10,000 volt breakdown test, while a large insulator should have to stand more. Again, I find that the difficulty with most trolley line insulators is that long before the breakdown point occurs the voltage will jump across the surface. We have found this difficulty to a great extent, not when the insulator is in its ideal condition; that is, perfectly dry and quiet and nice in the factory, but when you get it outside and expose it to the weather for quite a while.

As I have said, the matter of resistance of the insulators is governed greatly by the ingredients used. Almost any kind of insulation when dry will show high resistance. It takes but very little good shellac and good mica, or similar material of good quality, well bound together by binding material, to give you a pretty good high insulation resistance, dry and perfectly handled; but put it out on the line, let the thing crack, let a little moisture creep in, and that is the time when you want to get your insulation resistance. Insulators which look on the laboratory instrument absolutely perfect, when subjected to even a short period of service soon show very low insulation resistance. In considering standard specifications for trolley insulators, therefore, I want to suggest the following:

Continued service insulation cannot be determined by dry insulation tests.

Internal dielectric strength is more readily obtained than a satisfactory surface insulation.

A low temperature strain test is of little value to obtain the service strain resistance of a moulded strain insulator.

Strain insulators should hold together and insulate under strain and with moulded insulation removed.

MR. RALPH D. MERSHON:—Just one point in regard to this paper. I notice the tests were made with alternating current. It seems to me the insulators would have shown up better if the tests had been made with direct current, as insulators of this type, made with shellac, soften to a greater or less extent with alternating current. I made a test some time ago of the material used in such insulators, and found this softening effect in a marked degree. We tested in order to get a general idea as to the difference in the behavior of the insulators with alternating and direct current of the same voltage. The heating was much more marked with the alternating current. With it the insulator softened and broke down after a time, whereas on the direct current it was apparently good for an indefinite period.

MR. SACHS:—May I ask what the voltage was at which you tested the insulators, and the frequency?

MR. MERSHON:—They were tested at a number of voltages, and my recollection is that the frequency was 60 cycles. We tested them at 500 volts, direct current and 500 volts alternating current, noting the difference in the effect in the two cases. The insulators heated up very considerably on the alternating current, whereas they showed no signs of heating on the direct current?

MR. SACHS:—What was the duration of the test?

MR. MERSHON:—As I recollect, it was several minutes before you could feel that the insulator was getting warm with the alternating current.

DR. SHELDON:—I think that the breakdown test is properly made with the alternating current, because when the insulator is subjected to the inductive kick which has been spoken of, the effect is much more like that due to an alternating current than that due to a direct current; as regards the measurement of these resistances by this method, the surface leakage is taken into account.

MR. MERSHON:—It seems to me that the breakdown test with alternating voltage is not the proper one, for the reason that an element comes in of which I think Dr. Sheldon has not taken account—the hysteretic loss, which heats and softens the insulation, thus causing it to break down, where with the same direct current electrical stress it would not break down. That is to say, you might put on a direct current which would have the same value of kick that Dr. Sheldon speaks, of and not break down the insulator at all, whereas if you put on an alternating current of considerably less maximum voltage, it might break down, depending on the frequency and how long you kept the voltage on.

MR. SACHS:—I have recently made a series of tests on some insulations at high potentials in oil baths. I found, in every case where the potential had remained on the insulating piece for quite a while and then punctured, indications of softening right close to the electrodes. So that certainly would bear out what Mr. Mershon says regarding the heat effects.

A paper read at the 20th Annual Convention of the American Institute of Electrical Engineers Niagara Falls, N. Y., June 30, 1903.

THE STORAGE-BATTERY IN SUBSTATIONS.

BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

The rapid development of interurban electric traction has brought with it a new field for the economic utilization of the storage-battery. Inasmuch as in interurban electric traction it is the practice to develop the energy for the operation of any one system in one or two large generating stations and to distribute this energy to the trains through the medium of substations, in these substations the storage-battery has found a place as an equalizer. The function of the storage-battery is here to take care of the heavy loads or of the peaks of the demands which are made on the substations by the trains, and by absorbing energy from the central station at times of low demand, to smooth out the central station load line, filling up the hollows and cutting off the peaks.

The present paper deals with tests which were made on a large interurban system equipped with nine substations, and the data accumulated shows in a variety of ways the character of the demands which the storage-battery has to meet in substation practice. The data may be said to reveal as many of the faults as of the benefits of the storage-battery in substation practice, and as the intent of all of our engineering investigations is to improve conditions of operation, the faults which have been detected may prove as valuable from having been brought to light as are the measures which are given of the work done by the storage-batteries in improving the general economy of the system.

The tests described were made during the spring of 1902 on

the system of the Union Traction Company of Indiana. This company was organized June, 28 1899, and is the consolidation of the Union Traction Company of Anderson, and the Muncie, Anderson and Indianapolis Street Railway Company. Later by the purchase of the local lines of Marion and the building of inter-

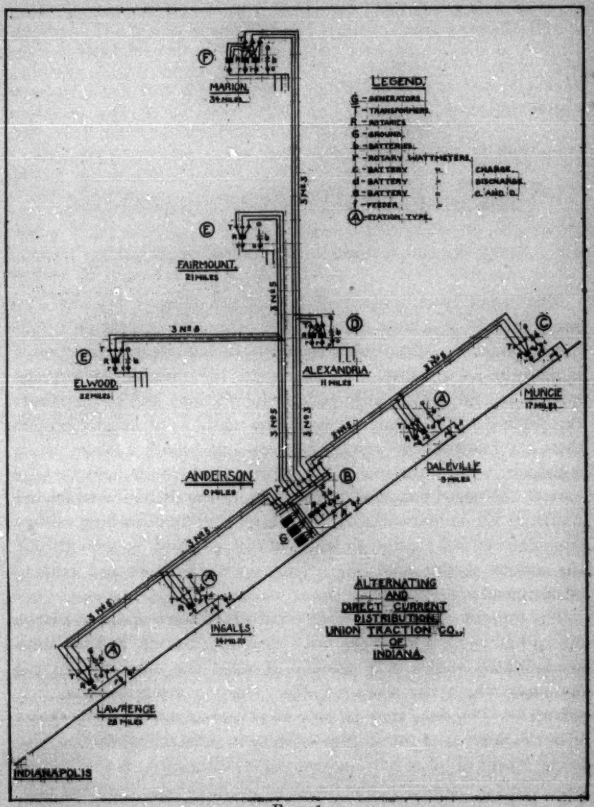


FIG. 1.

urban lines the system has been extended until at the time of the tests it was operating over 160 miles of city and interurban track. About 110 miles of this is interurban road connecting the principal cities of the Indiana gas belt and its location is shown by the

chart of Fig. 1, in which diagrammatical representation is given of the transmitting and distributing lines which connect the distributing substations. At the present time this system is greatly extended over what it was at the time of the tests and represents the greatest interurban property in the world. The main power station at which all the power for the entire system is generated is located at North Anderson, adjacent to the interurban line. The substations have been installed at Lawrence, Ingalls, in the main station at Anderson, at Daleville, Muncie, Alexandria, Fairmount, Marion and Elwood.

At the central station the generators deliver electric energy to the load bus-bars at 400 volts. It is then stepped up to 16,000, and transmitted at this potential to the substations, where it is stepped down to 330 volts. Rotary converters then transform the energy from alternating at 330 volts to direct current at 550 volts, the latter being the pressure used on the trolley system. The substation at Ingalls is 15 miles from Anderson, that at Lawrence 28½ miles. These substations receive energy from the same high tension feeders. The substation at Daleville is 9 miles and that at Muncie 18 miles from the central station. These two stations are also on the same set of high-tension feeders. Alexandria is 11 miles and Fairmount 21 miles from the central station; the substations at these points receive energy from the same set of high-tension feeders. Marion, which is 33 miles from Anderson, and Elwood, which is 21 miles from Anderson, have substations receiving energy in part over the same high-tension feeders. The feeder system supplying these stations branches at Alexandria, one section continuing north and the other due west.

The several sets of high-tension feeders consist of three No. 5 bare B. S. wires. The substation equipment at Anderson consists of three 250 k.w. rotary converters, a 20 k.w. booster unit and a storage battery of 264 chloride cells having a one hour capacity of 400 amps. and an 8 hour capacity of 100 amps. In this substation a portion of the low potential current from the main generators is led to the rotary converters through auto-transformers instead of through the fifteen 250 k.w. static step-up transformers. Of these 15 static step-up transformers only 12 are kept in service, the other three being a reserve. The substations at Lawrence, Ingalls, Daleville, Fairmount and Elwood are each equipped with three 87.5 k.w. static step-down transformers, one rotary converter of 250 k.w. capacity, a battery of 264

chloride cells, having a one hour capacity of 160 amps. and an 8 hour capacity of 40 amps., and one 8 k.w. booster. The remaining substations, namely those at Muncie, Alexandria and Marion are equipped with four 175 k.w. static step-down transformers (one being held in reserve), two 250 k.w. three-phase rotary converters, one 16 k.w. booster unit and a storage-battery of 264 chloride cells, having a capacity of 320 amps. at a one hour rate and 80 amps. at an eight hour rate.

The high-tension lines both at the central station and the substations are protected by high-tension lightning arresters and the static transformers are oil-cooled.

A portable substation, equipped with three 87.5 k.w. static step-down transformers, one 250 k.w. rotary converter and a switchboard, has been built for use in case of an emergency arising from accident to one of the rotary converters or for temporarily increasing the capacity of any one of the established substations. Track has been laid into the substations so that this portable substation car may be run directly into any one of the converter rooms and its rotary leads connected to the direct current line in the same manner as are the regular substation machines. At the time of the test the portable substation was in use at Marion increasing the capacity of the Marion substation, where the load was temporarily in excess of the rated capacity of the equipment. The substation buildings are all of the same construction. In addition to the equipment just specified the substations contain switchboards of white marble, which consist of one A.C. panel and one D.C. panel for each rotary installed, two battery and booster panels and one D.C. panel for each feeder leaving the station. The station instruments are mounted on the switchboards and consist of three A.C. ammeters, one in each leg of the three-phase lines, one D.C. ammeter, voltmeter and wattmeter for each rotary, one D.C. ammeter and voltmeter for the battery and one D.C. ammeter for each D.C. feeder panel. Automatic circuit-breakers and lightning-arresters are provided for outgoing lines.

The substations were equipped with recording wattmeters in addition to those permanently mounted on the switchboards. These are indicated in Fig. 1. For instance the substations at Ingalls, Lawrence and Daleville have a switchboard recording wattmeter (r) which registers the rotary output, and a temporary recording wattmeter (c) for registering the battery charge and a temporary recording wattmeter (d) for registering the battery discharge. The wattmeters (c) and (d) were controlled

by a switch which connected the pressure-coil of the wattmeter (*c*) in circuit when the battery was charging and connected the pressure coil of the wattmeter (*d*) in circuit when the battery was discharging. A special observer controlled the position of this switch in accordance with the indications of the battery switchboard ammeter. At Anderson one switchboard recording wattmeter (*r*) registered the output of the three rotaries, the battery charge and discharge being determined by two wattmeters in the same way as at Lawrence, Ingalls and Daleville.

As the Anderson substation supplied power to the local lines in addition to the interurban lines, two special wattmeters (*f* and *f*) were placed in the feeders extending east and west from Anderson. At Muncie two switchboard recording wattmeters are supplied for determining the output of the two rotaries in this substation. The battery charge and discharge was determined by two recording wattmeters (*c* and *d*) as at Lawrence, Ingalls and Daleville, with the addition of the recording wattmeter (*e*) which was permanently connected in the battery lead so that it ran forward when the battery was charging and backward when the battery was discharging. The recording wattmeter (*f*) placed in the interurban feeder registered the amount of the output of the Muncie substation which was delivered to the interurban cars. This substation also supplied the cars of the local line with power. At Elwood and Fairmount the rotary output was determined by the switchboard recording wattmeter (*e*) permanently connected in the battery lead. At Alexandria the same conditions existed as at Elwood and Fairmount except that two switchboard recording wattmeters are provided for determining the rotary output. At Marion the same conditions obtained as at Alexandria except that an additional recording wattmeter (*p*) was placed in the portable substation to determine the output of the rotary. In all, therefore, there were twelve switchboard recording wattmeters in use for determining the output of the rotaries and one temporary recording wattmeter for determining the output of the portable substation rotary. Fifteen temporary recording wattmeters were used for determining the charge and discharge of the storage batteries and three special feeder recording wattmeters for determining the proportions of the output of the Anderson and Muncie substations which were delivered to the interurban feeders.

During the tests the D.C. instruments which have been mentioned, except the feeder ammeters, were read in all of the sub-

stations every fifteen minutes. Simultaneously with these readings a polyphase recording wattmeter, which registered the central station output, was read and readings were also taken from recording wattmeters placed in each one of the interurban cars plying between Indianapolis and Muncie.

All of the instruments used in the test were carefully calibrated by being compared with standards. The method of calibrating the recording wattmeters was as follows: the time was taken during which a certain number of revolutions of a wattmeter-disc were made, while during the same time rapid observations were made of the current and voltage fluctuations. From the latter the average of the current and voltage during the time the revolutions of the wattmeter disc were being made were determined. The constant of the wattmeter is found by the formula:

$$K = \frac{\text{Watt hours}}{\text{revolutions}} = \frac{E \times I \times T}{3600 \times R}$$

Where E is the average voltage,
I the average current,
T the time in seconds,
and R the number of revolutions of the disc.

The wattmeters were all calibrated while connected in with the service lines. The constants determined for many of the wattmeters differed widely from those given by the manufacturers. This is probably due to the fact that in many cases the wattmeters ran far below their rated current capacity. This was unavoidable on account of the fact that the capacity of the wattmeters had to be sufficient to take the peak loads. Where the wattmeter was permanently connected in the storage battery leads, as at Muncie, Alexandria, Fairmount, Marion and Elwood, so that it ran both forward and backward, the instrument had to be calibrated for both methods of operation. It was found that the constants of these instruments when running forward were quite different from the constants of the instruments when running backward.

The polyphase wattmeter at the power house was also calibrated, and as the calibration showed its error was probably not greater than those of observation, its readings were assumed to be correct.

Efficiency of High and Low-Tension Distribution Lines.

The arrangement of the high-tension feeders between the central station at Anderson and the several substations, has

already been described. In determining the efficiency of the high tension distribution system recourse is had to the central and substation records. In Table I. the total outputs of the rotaries in the different substations for the different days of the test are recorded. In Table II. that part of the total output of the main generating station at Anderson is recorded which was delivered to the primary windings of the high-tension transformers. These values are equal to the total output of the generating units as given by the recording wattmeter on the load panel, less the power taken from the primary bus-bars by the rotaries located in the generating station. Table II. also records the total power delivered to the low-tension feeders by the substations which derived their energy from the high-tension system. The D.C. output of Table II. is therefore the sum of the readings of all the rotary wattmeters less the output of the rotaries in the Anderson substation, as these were fed directly from the generating station bus-bars through auto-transformers and not through the high-tension lines. The all-day efficiencies obtained run very close together, averaging 73½ per cent.; this is the efficiency of the high-tension distribution from the low-tension bus-bars in the generating station to the direct current terminals of the rotaries.

In determining the efficiency of the high-tension transmission lines, the amount of energy lost in the raising and lowering transformers, as well as in the rotary converters, had, of necessity, to be determined. The transformers were not worked up to their full capacity; the load on the single, or A and B. stations, Fig. 1, averaging about 40 per cent., the load on the Muncie station averaging about 34 per cent. and that on the Alexandria and Marion stations but 30 per cent. of the total full load capacity of the transformers. By an inspection of the transformer efficiency curve supplied by the manufacturers, it is estimated that the average efficiency at which the transformers worked is not far from 95 per cent. and, as recorded in Table IV., this value has been used. To obtain the average working efficiency of the rotary converters, a special test was made on the rotaries in the Alexandria substation, beginning on April 27th and ending on April 30th. In arranging for this test an alternating current recording wattmeter was connected in each of the three alternating current leads of one of the rotaries. The sum of the readings of these wattmeters gave the rotary input, while the output was given by the regular direct current station recording wattmeter:

the instruments were read every hour. From these two sets of readings the efficiency was estimated by determining the ratio of the output to the input of the rotaries over selected periods of one, six and twelve hours; the results of these efficiency determinations are given in Table III. and plotted in Fig. 25. It will be observed that the load on the rotary under test varied from 23 to 54 per cent. of the capacity of the rotary, and that the average of the efficiency record is practically 88 per cent.; and since all of the rotaries installed are identical in design and construction, it may be safely assumed that the efficiency as determined above for one rotary is applicable to all the rest of the rotaries. Further, the average load on the substations varied between 30 and 40 per cent. of the capacity of the rotaires in the several substations, and, therefore, the records in Table III. show that the rotary under test was subjected to an average degree of loading. The figure, 88 per cent., has been used, as recorded in Table IV., in determining the energy lost in the rotaries.

Having the transformer and rotary efficiencies estimated with a fair degree of accuracy, it was a simple matter to determine the input to the high-tension line from the input to the step-up transformers, and the output from the high-tension line from the output of the rotaries. Taking the ratio of these values we find that the average efficiency of the high-tension distributing system is 93 per cent., being practically constant for the three days. This result indicates that the efficiency of the high-tension system in operation is somewhat less than the efficiency for which it was calculated. When installed it was estimated that the high-tension lines would absorb 7 per cent. of the energy transmitted when the system was working under full load; inasmuch as the average load was not in excess of 40 per cent. of the capacity of the system, the efficiency shown by the test is lower than what would be expected.

In determining the efficiency of the low-tension distributing system, the ratio is taken of the total power delivered to the cars to the total power delivered into the low-tension feeders from the substations. The determination of the amount of power supplied by the substations to the low-tension distributing system is given in Table V. Owing to the fact that it was only possible to equip the interurban cars plying between Indianapolis and Muncie with the recording wattmeters, the efficiency of only this portion of the low-tension transmission system was made. On account of the fact that the Muncie substation supplied the

power for the local cars in Muncie, it was necessary to install a special recording wattmeter in the interurban feeder from the Muncie substation. The Anderson substation also supplied power for the operation of the local cars in Anderson; and accordingly a wattmeter had to be placed in the feeders which run East and West from the Anderson substation supplying power to the interurban cars.

Circuit-breakers were inserted at the city limits in Muncie and in Anderson. This arrangement effectively prevented any error entering into the efficiency determinations, inasmuch as the wattmeters on the interurban cars were read whenever these circuit-breakers were passed. In determining the power delivered to the low-tension distributing system from the substations, the battery charges were in each case subtracted from the sum of the rotary outputs and the battery discharges, except in the case of the Anderson and Muncie substations where the results were obtained directly from the feeder wattmeters. The results of the efficiency determinations show that the efficiency of the low-tension distribution system over the Anderson-Muncie division is about 5 per cent.. higher than that over the Indianopolis-Anderson division. The loss of the former amounts to about 22 per cent. and that of the latter about 28 per cent. of the energy delivered to the low-tension feeders. The average efficiency of the low-tension transmission for the three days of the test over the Muncie-Indianapolis lines was 74½ per cent., which shows a loss in the distributing system of 25½ per cent. of the energy delivered by the substations to the feeders.

Storage Battery Tests.

Having obtained a fair understanding of the conditions which existed over the system, we can now profitably turn to the records which were made of the storage-battery performances in the various substations. The connections in the substations are shown in Fig. 26. From these it will be seen that the booster is so connected in the battery circuit as automatically to adjust the battery voltage to the demand on the substation; in other words, the battery charges and discharges automatically, feeding out to the line when the demand is above a given amount, and being charged by the rotaries when the demand falls below that amount. The potential at which the battery will float on the system, or the demand on the system corresponding to which the battery is inactive, can be adjusted at any desired point by the switchboard attendant; this fact is to be remembered in connection with the data which is presented.

Prior to the main test, a special test was made of the storage-battery in the Ingalls substation on the 23d of March, 1902, between 8.15 A. M., and 8.00 P. M. The record of the rotary output during this time is given in Fig. 2; the battery current and the battery and line voltage are not plotted in Fig. 2, but these quantities are given in Fig. 3 for the period of the test between 5.00 and 7.00 o'clock. The results are plotted to a much larger time-scale in Fig. 3 than in Fig. 2, and more perfectly show the load variations.

The records in Fig. 2 are given to show the load cycle on the Ingalls substation. The cycle is caused by the manner in which the local interurban cars and the limited interurban cars pass the substation. At the even hour the local interurban cars running both East and West are so far from the station as to make but a slight demand upon it for power; however, at twenty-five minutes past the hour a local interurban car passes going East and at thirty-five minutes past the hour another passes going West; this cycle was repeated each hour. The limited interurban cars approach and pass the station just before and just after the even hours every third hour, *i.e.*, at five minutes to twelve a limited car passes the station going East, and at five minutes past twelve a limited car passes the station going West; at five minutes to three another limited passes the station going East, and at five minutes past three a limited passes the station going West. By the letters I E for the local interurban going East and I W for the local interurban going West, by L E for the limited interurban going East and L W for the limited interurban going West, the times at which the interurban cars pass the Ingalls substation are indicated on Fig. 2. It will be noted that the points of maximum demand usually fall about the time (according to the schedule) the cars should be passing the substation.

The maximum capacity of the rotary of this substation is 500 amperes, and it will be noted that the load on the rotary during the twelve-hour test rarely exceeded this maximum amount, the average load being between 200 and 250 amperes. The readings from which these curves are plotted were taken with great care, Fig. 2 being plotted from readings taken at thirty-second intervals and Fig. 3 from readings taken at fifteen-second intervals. In Fig. 3 the battery current and the rotary current are shown by full lines. The algebraic sum of the battery and rotary currents give the dotted line which crosses the rotary current line; this

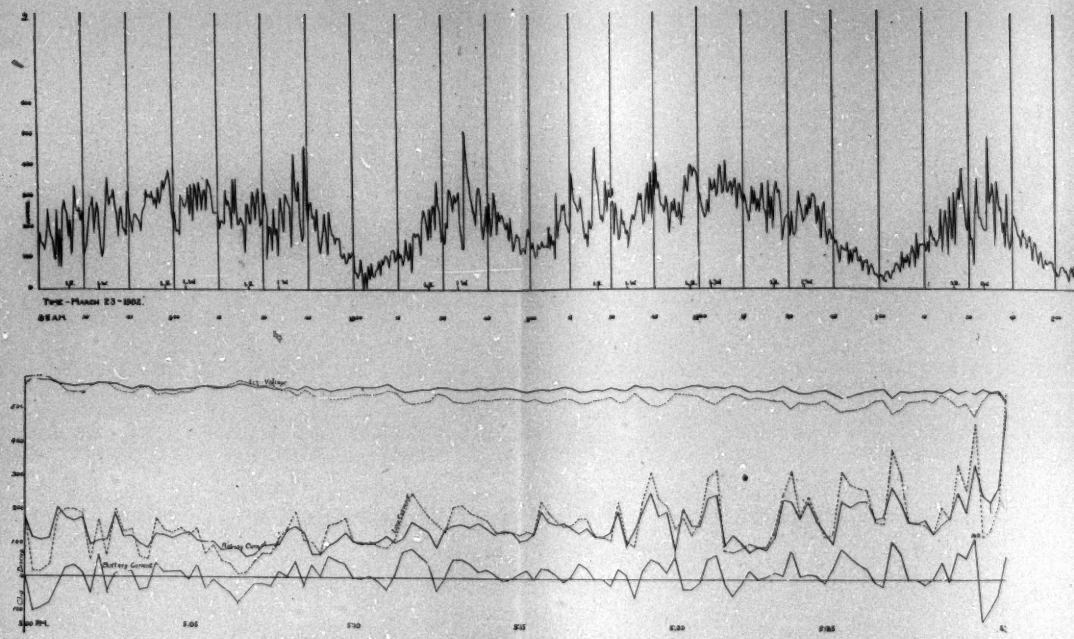

TIME - MARCH 23 - 1902.
Arc Voltage
Arc Current
Battery Current

Fig. 3 A.

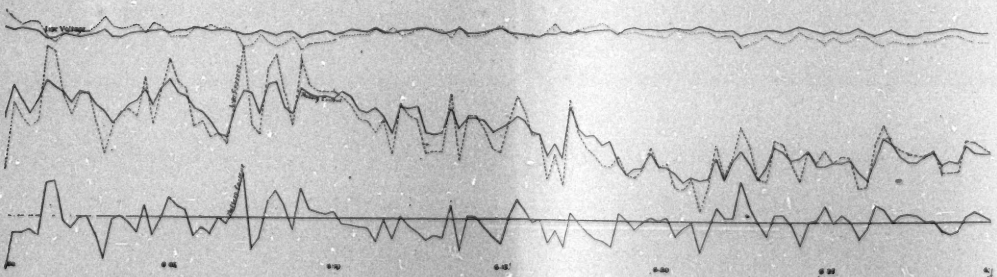

Arc Voltage
Arc Current
Battery Current

Fig. 3 C.

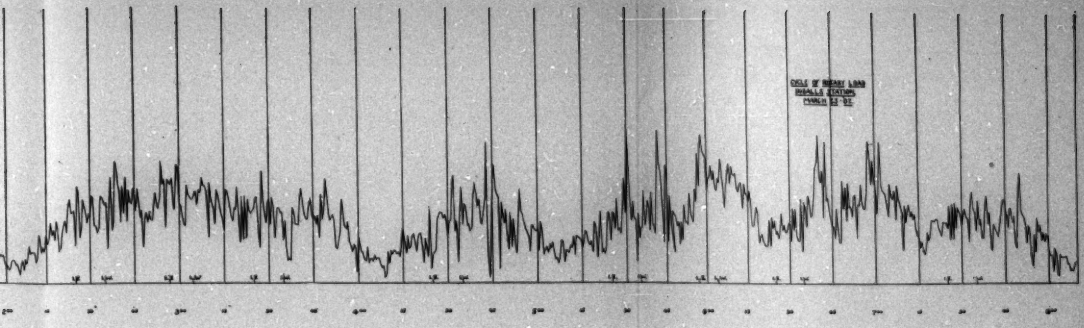


Fig. 2.

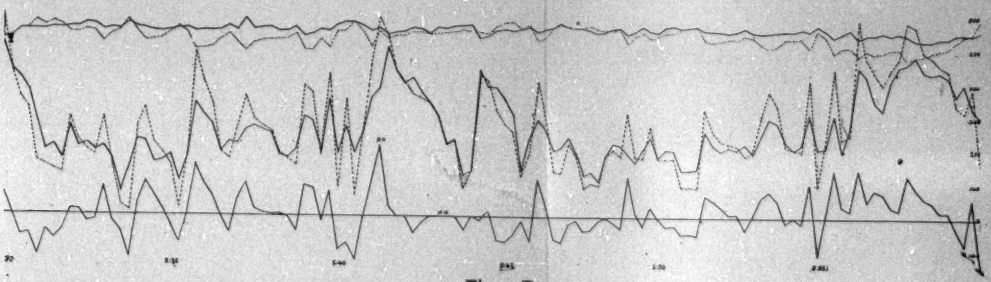


Fig. 3 B.

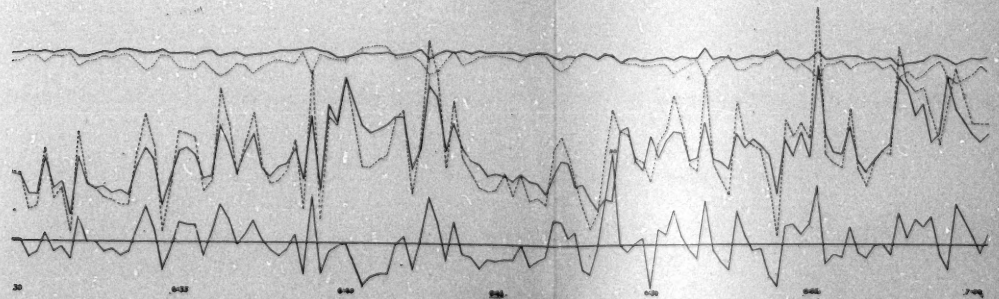


Fig. 3 D.

dotted line shows the total demand on the substation by the trains. The line voltage is shown by a full curve at the top of the chart, the dotted curve being the battery voltage. The maximum discharge rate for one hour of the battery in the Ingalls substation is 160 amperes. The maximum demand made upon the battery in one instance was as high as 270 amperes and in another ran up to 175 amperes; in general, however, the demand upon the battery was not especially heavy, not often exceeding 100 amperes, and, frequently for a considerable period of time falling within the eight-hour discharge rate of 40 amperes. The greatest instantaneous demand on the station recorded in Fig. 3 occurred at 6.55 P. M., when the load momentarily ran up to 700 amperes. The accuracy of the results plotted in Fig. 3 is indicated by the fact that when the battery is discharging the battery voltage always drops below the line voltage, and, that when the battery is charging, the battery voltage runs above the line voltage.

The curves of Fig. 3 have been made chiefly useful in determining the "*efficiency of equalization*," of the battery in this substation. The efficiency of equalization designates the extent to which a storage-battery is successful in maintaining the demand on a rotary converter or generator at the true average of the load under the variable conditions of service. If a line be drawn that represents the average load on a station and the rotary load curve coincides with it, the battery may be said to have an "efficiency of equalization of 100 per cent."; *i.e.*, it performs its function as an equalizer perfectly. On the other hand, if the rotary curve follows the line load curve, the battery is obviously inactive, and, therefore, its efficiency of equalization is zero. The efficiency of equalization may then be defined as the ratio of that portion of the rotary load-curve that is above the average load curve to that portion of the line load curve that is above the average load-curve. In the present instance the efficiency of equalization of the battery works out to be 11.9 per cent.; *i.e.*, the battery only reduces the irregularities in the demand on the substation from the line by 11.9 per cent. of what the demand on the rotaries would be if the battery so equalized the load that the rotaries worked constantly under a load equal to the average of the variable demand made upon the substation by the cars.

The result of these considerations indicates that the adjustment in the substation was somewhat faulty; the booster and battery are not so arranged as to enable the battery to respond with sufficient promptness in taking care of variations in the load

which occur. It is not a case of the battery not having sufficient capacity for the duty which it is called upon to perform, as the maximum variations in the load seldom exceed 250 amperes and more frequently run within 150 amperes. No attempt was made to remedy the faulty action of the booster set, as until the recorded data could be worked up no estimate could be made of the performance of the battery in this particular.

In order to determine the duty performed by the boosters in the substations, a determination has been made from the readings taken in the Lawrence substation during the main test of the average amount of boosting done by the booster during each of the three days. On the first day, April 17th, the line voltage averaged 15.5 volts higher than the battery voltage; on the second day, the line voltage averaged 31 volts higher than the battery voltage and on the third day 10.6 volts higher than the battery voltage. The Ingalls and Lawrence substations, as indicated by Table I., have about the same rotary output in k.w. hours per day. The average current demand made on these substations is not far from 175 amperes and, consequently, the normal demand made upon the boosters is from 1.75 to 5.25 k.w. The capacity of the boosters in the Ingalls and Lawrence substations is 8 k.w., and it is probable that very frequently so heavy a demand is made upon the boosters that they have not the capacity to enable them adequately to meet the demand. If the boosters had been equipped with a heavy flywheel, the chances are that the "efficiency of equalization" of the storage-battery would be very greatly improved over what the results recorded make it possible to report.

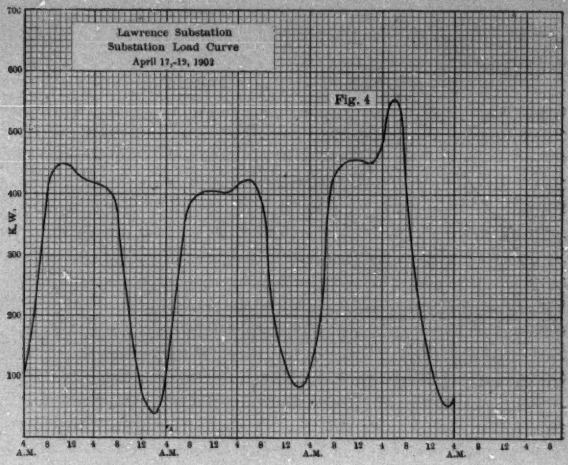
At the time of planning for the tests which were made on the storage-battery it was hoped that data would be accumulated which would make it possible to determine the exact commercial efficiency of the storage-battery equipments of the various substations. When, however, it is remembered that it was not possible to subject the storage-batteries to any definite cycle of loading and that it is extremely difficult when a definite cycle of loading does not exist to keep a sufficiently accurate hold on the battery to admit of its being brought to the same condition once in 24 hours, the difficulties in the way of obtaining any accurate efficiency estimates are at once apparent.

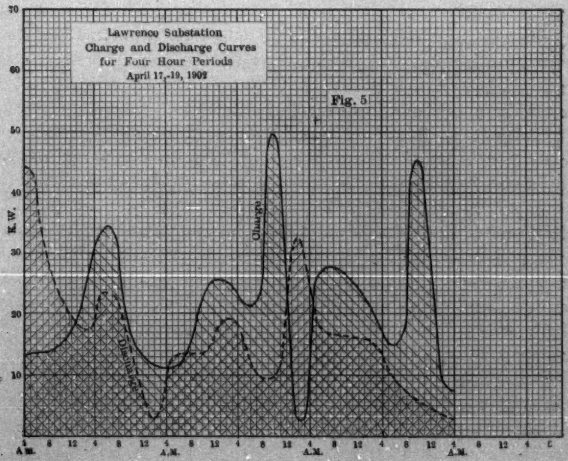
In scanning the records efforts were made to obtain efficiency indications by a comparison of wattmeter readings made at times when the battery current was zero and the voltage the

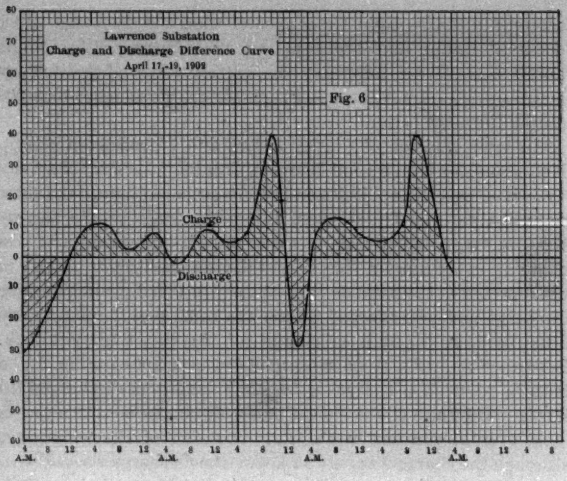
same, on the assumption that within reasonably short periods of time the variations in the battery solution would not be sufficient to affect the results materially. Inspection, however, proved that the variations which took place in the load upon the battery were entirely too rapid for the voltage record to be sufficiently reliable for the purpose contemplated, and, therefore, all attempts to determine the performance of the batteries in terms of commercial efficiency were abandoned. In lieu of these determinations an effort has been made, by virtue of the presentation of the recorded data which is given in Figs. 4 to 23, to throw some light on the service which the different batteries were required to render.

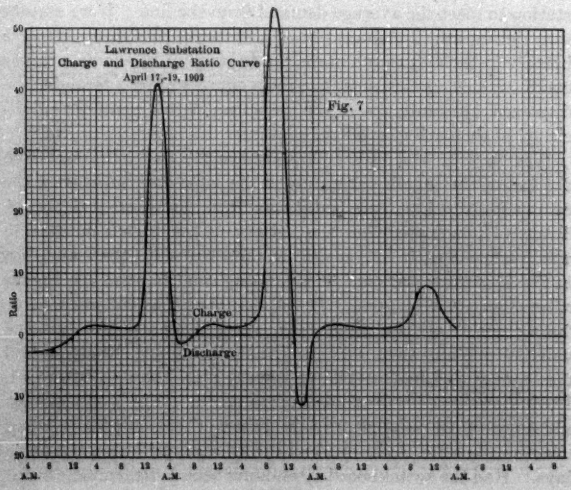
Figs. 4, 5, 6 and 7 relate to the battery in the Lawrence substation. Fig. 4 is the load curve for the three days of the test on this battery. The ordinates represent the k.w. hour load for 4-hour periods plotted above the mean time of the period. For instance, the ordinate which determines the peak in the afternoon of the third day gives the k.w. hour output of the substation between 4 and 8 P. M., and is plotted over the 6 P. M. abscissa. The curves of Fig. 4 therefore indicate the demand made on the substation by the cars during 4-hour periods. In Fig. 5 the charge and discharge of the Lawrence substation battery is also shown for 4-hour periods. For instance, during almost any period of four hours the battery is both charged and discharged and the total charge and discharge values common to a 4-hour period are plotted over the center on that period. For instance, the charge between 12 and 4 P. M. of the second day was 26 k.w. hours and the discharge during the same period was 19 k.w. hours.

The curves of Fig. 6 show the excess of the charge over the discharge or of the discharge over the charge in k.w. hours for 4-hour periods. In other words, the areas of Fig. 6 are the algebraic differences of the charge and discharge areas of Fig. 5. From these, therefore, we can determine the total charge or discharge over the discharge or charge for any 4-hour period. For instance, between 8 and 12 P. M. of the second day the battery had an excess of charge over discharge equal to 40 k.w. hours, while between 12 and 4 A. M. of the third day the battery was discharged more than it was charged by an amount of 30 k.w. hours. Fig. 7 shows the rate at which the battery was charged or discharged in excess of the discharge or charge during any 4-hour period. For instance between 8 and 12 P. M of the third day the battery


Lawrence Substation
Substation Load Curve
April 17,-19, 1902
Fig. 4
K.W.
700
600
500
400
300
200
100
A.M.


Lawrence Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
Fig. 5
K.W.
70
60
50
40
30
20
10
Charge
A.M.


Lawrence Substation
Charge and Discharge Difference Curve
April 17,-19, 1902
Fig. 6
Charge
Discharge
A.M.


Lawrence Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Fig. 7
Ratio
Charge
Discharge
A.M.

received a charge eight times greater than the discharge which occurred during this 4-hour period, while between 12 midnight and 4 A. M. of the third day the battery received a discharge which was eleven times greater than the charge which it received during the same period.

An interpretation of Curves 4, 5, 6 and 7 considered collectively indicates with a good degree of accuracy the kind of service which the Lawrence substation battery rendered during the three days of the test. On the first day in the forenoon the battery was discharged more than it was charged, but the rate of discharging in the morning of the first day was not great. Early in the morning of the third day the battery received about the same discharge and was charged during the same period only a very little, so that the rate of charge for this time was quite high. Between 8 and 12 P. M. of the second day, as shown by Fig. 5, the battery received a charge of 50 k.w.h. and was discharged 10 k.w.h. The ratio of the charge to the discharge is in this case a little over 5, whereas in the early morning of the same day, although the charge was only 12 k.w.h. the discharge was 3 k.w.h. and therefore the rate of charge over discharge a little over 4. The value of the ratio curves is in determining the accuracy with which the switchboard attendant adjusts conditions in his substation to meet the average demand from the line. If we assume that during any four hour period the charge and discharge of a battery is such as to maintain the battery in the same average condition during this time, the ratio curve will be a straight line displaced 1¼ points above the zero line, if the commercial efficiency of the battery is 80 per cent.

Figs. 8, 9, 10 and 11 are plotted from the data obtained from the test of the Ingalls substation in the same manner as were the curves for the Lawrence substation just discussed. However, Table VII. indicates that the battery in the Ingalls substation was worked a little harder during the three days than was that in the Lawrence station. The working conditions in the Ingalls substation are very good. It will be noted that the ratio curve during most of the time runs along between the positive value of one and two, indicating that during any 4-hour period the battery was made to charge slightly more than it discharged. The performance for the three days as shown in Fig. 7 indicates an efficiency of 74 per cent. for the battery; this efficiency being taken as the ratio of the charge to the discharge during the three days. Had the switchboard attendants been a little more careful

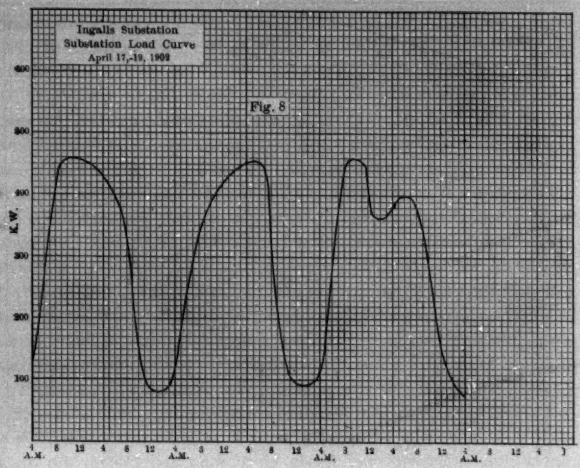

Ingalls Substation
Substation Load Curve
April 17,-19, 1902
K.W.
A.M.

Fig. 8

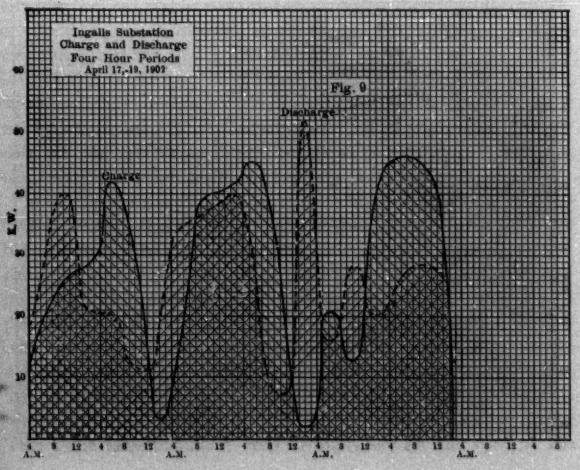
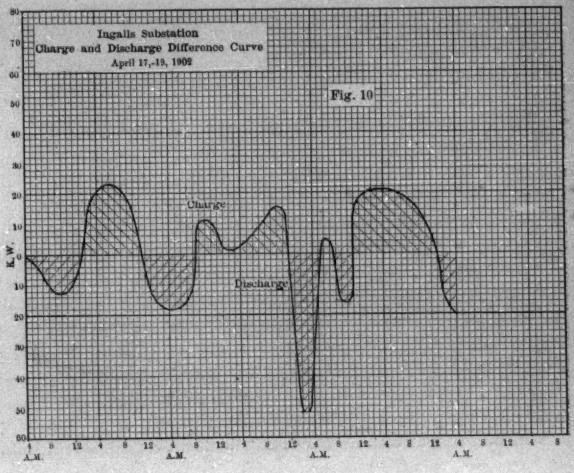
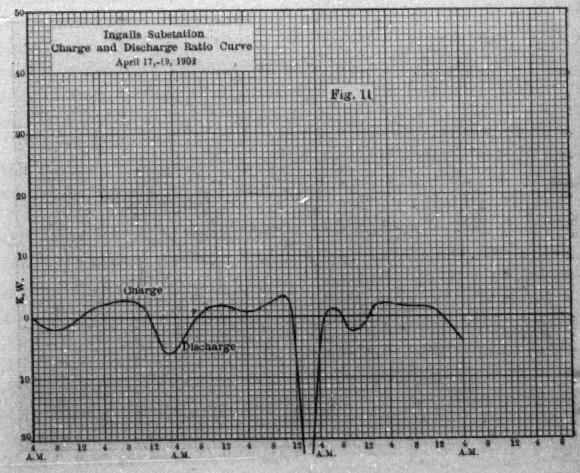

Ingalls Substation
Charge and Discharge
Four Hour Periods
April 17,-19, 1902
Discharge
Charge
K.W.
A.M.

Fig. 9


Ingalls Substation
Charge and Discharge Difference Curve
April 17,-19, 1902
Fig. 10
Charge
Discharge
K. W.
A.M.
A.M.
A.M.
A.M.

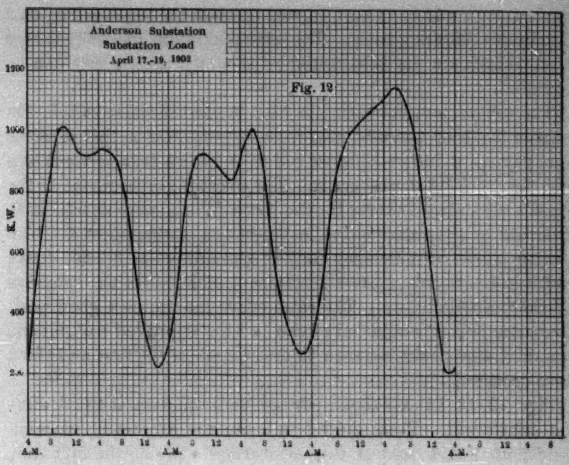

Ingalls Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Fig. 11
Charge
Discharge
K. W.
A.M.
A.M.
A.M.
A.M.

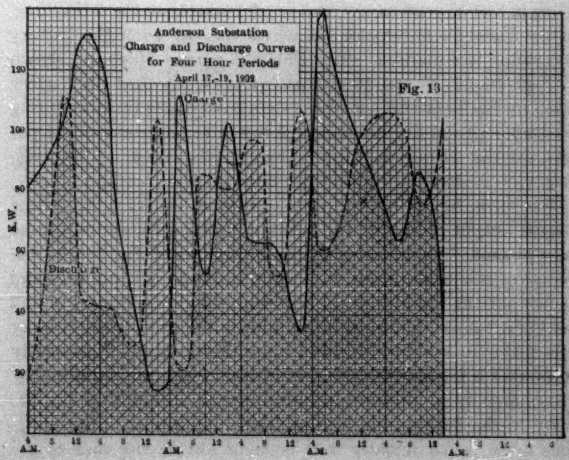
the battery could have been carried through the test working on a maximum efficiency basis. The term maximum efficiency is here used to indicate the best efficiency at which the battery can be operated.

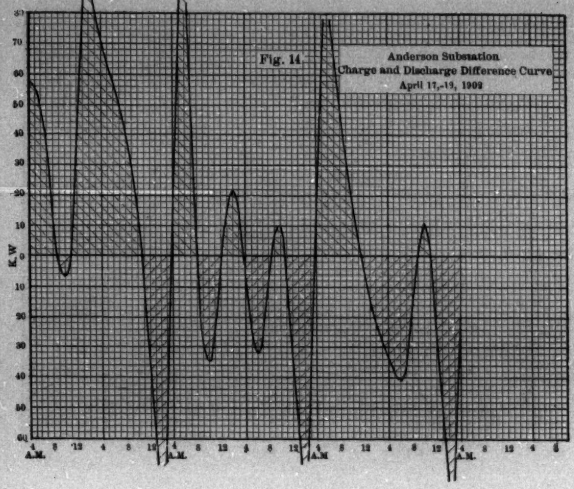
The 4-hour period which has been made the basis in this discussion has been assumed arbitrarily, for the reason that it seems long enough to insure a proper gauge of the average performance and not too long to obscure it. The average performance of the Ingalls substation battery for the three days is more nearly what it should be than that of any other of the stations tested. The station shows an efficiency for the three days of 88 per cent., which is 3 per cent. above the efficiency claimed for the batteries by the manufacturers. The ratio curve maintains a good positive value which would have been greatly improved had not the two discharge peaks between 12 and 4 A. M. of the first and third days occurred.

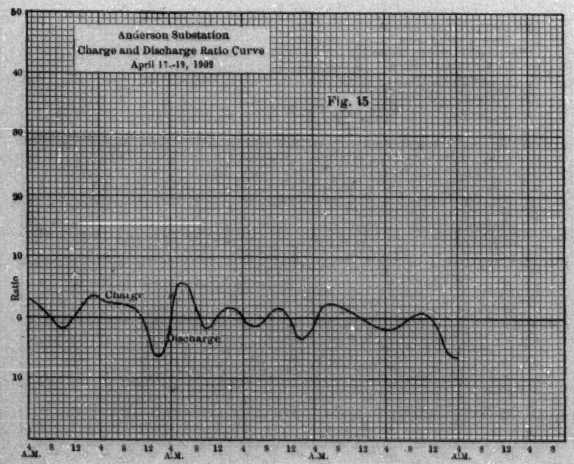
Figs. 12, 13, 14 and 15 are plotted from the data at the Anderson substation. These curves indicate the extremely variable conditions which exist at this substation owing to the fact that local and interurban cars bring about very irregular conditions of load. In spite of the fact that this battery shows heavier charge and discharge periods of long duration than that of any of the other substations, the ratio curve is comparatively good, being in fact as good as any, and much better than the ratio curve of the Daleville substation, in which the tax upon the battery was much less marked. The Daleville curves which are shown in Figs. 16, 17, 18 and 19 indicate quite clearly that the battery was practically floating on the system most of the time, as during no 4-hour period did its discharge over its charge exceed 14 per cent. of the 4-hour discharge rating of the battery. The efficiency of the battery for the three days is 76 per cent.

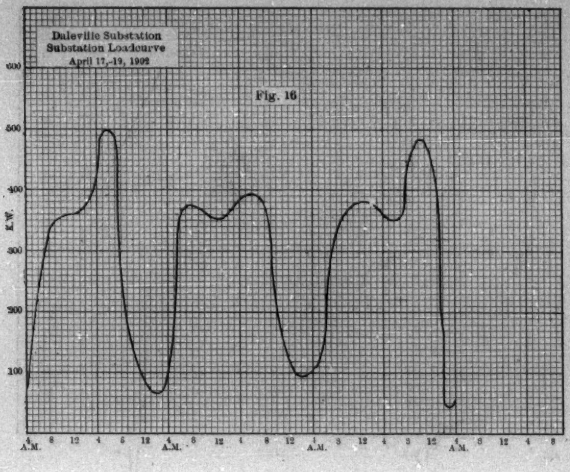
The substation at Muncie, next to that at Anderson, shows the largest output of any of the substations for which curves have been plotted. As indicated by the ratio curve of Fig. 23, the discharge of this battery was very much in excess of the charge and in fact for the three days the station shows an efficiency of 112 per cent. As at Anderson so at Muncie the local street railway cars make an irregular demand upon the station. This largely accounts for the fact that no special discharge cycle is noticeable. The charge cycle, however, is fairly regular as shown by Fig. 21. Most of the substations have a fairly uniform charging cycle. This cycle is particularly well brought out in the case of the

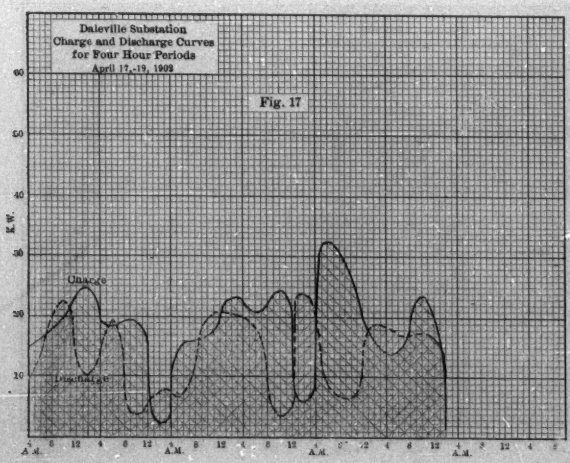

Anderson Substation
Substation Load
April 17,-19, 1902
Fig. 19
K.W.
1200
1000
800
600
400
200
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M. A.M. A.M. A.M.

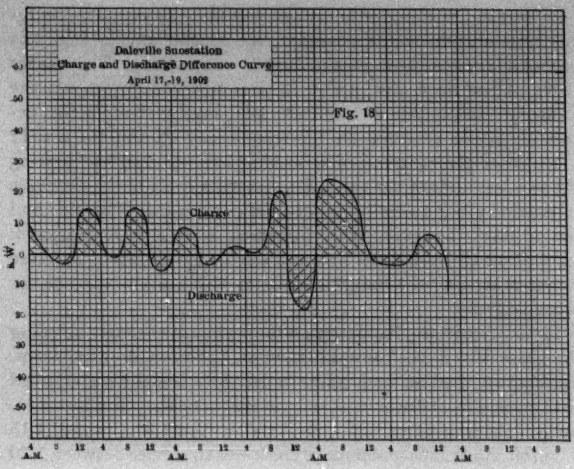

Anderson Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
Fig. 19
Charge
Discharge
K.W.
120
100
80
60
40
20
4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8 12 4 8
A.M. A.M. A.M. A.M.

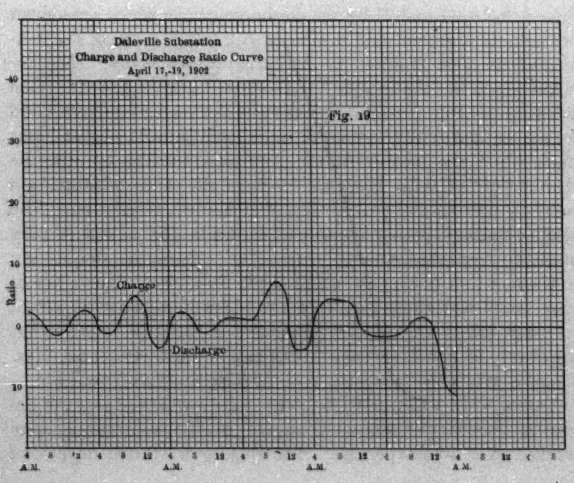

Anderson Substation
Charge and Discharge Difference Curve
April 17.-19, 1902
Fig. 14.
K.W
A.M.


Anderson Substation
Charge and Discharge Ratio Curve
April 17.-19, 1902
Fig. 15
Ratio
Charge
Discharge
A.M.


Daleville Substation
Substation Loadcurve
April 17,-19, 1902
Fig. 16
K.W.
600
500
400
300
200
100
A.M.
A.M.
A.M.
A.M.


Daleville Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
Fig. 17
K.W.
60
50
40
30
20
10
Charge
Discharge
A.M.
A.M.
A.M.
A.M.


Daleville Suostation
Charge and Discharge Difference Curve
April 17,-19, 1902
Fig. 18
Charge
Discharge
A. W.
A.M.
A.M.
A.M.
A.M.


Daleville Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Fig. 19
Charge
Discharge
Ratio
A.M.
A.M.
A.M.
A.M.

Lawrence substation on the second and third days. The charging cycle shown by the curves of the second day in Fig. 9 is probably characteristic of the Ingalls substation. The charge curve of the third day in Fig. 13, it is believed, represents the ordinary charge cycle of the Anderson battery; but for the depression which occurred on the second day during the 8 to 12 A. M. period the charging cycle would have repeated itself during the two last days of the test. The charging cycle of the Daleville substation is not specially characteristic in outline. The first and second days, however, show in general what is to be expected. In the case of Muncie the first and third days are probably more representative of the charging cycle in this station than is the second day.

It very frequently happens that for a while in the early morning the generators in the central station at Anderson are shut down. During these periods such trains as may be operating are supplied with energy from the substation storage batteries. For instance, none of the generators was in service between 1.30 A. M. and 4.15 A. M. on April 18th and none of them was in service between 1.30 A. M. and 4.15 A. M. on April 19th. Here then we have two periods of 2.75 hours during which such trains as were operated were supplied with power from the storage batteries. This condition of rest in the central station is reflected in the curves of Figs. 5, 9, 13, 17 and 21 by the discharge peaks which are shown between 12 midnight and 4 A. M. of April 19th. All of the batteries were then required to discharge quite heavily. The demand which was made upon the Lawrence, Ingalls and Anderson substations being particularly heavy. Between 12 midnight and 4 A. M. on April 18th, owing to some local cause a demand was made upon the battery in the Anderson substation. On the morning of the 18th, however, none of the other substations is carrying any special load except the Muncie substation. The Muncie battery discharge curve as shown in Fig. 21 differs very markedly from the discharge curves of the other substations owing to the fact that during the whole of the three days the average of four hours never falls below 44 k.w.h. nor rises above 85 k.w.h. In other words, this battery maintains a discharge rate averaging closely 58 k.w.h. for each 4-hour period during the three days. There is evidently " something doing " in Muncie all the time.

Tables VII., VIII. and IX. contain data which shows the degree to which the storage-batteries in the substations were worked over 4-hour periods. The Ingalls substation developed

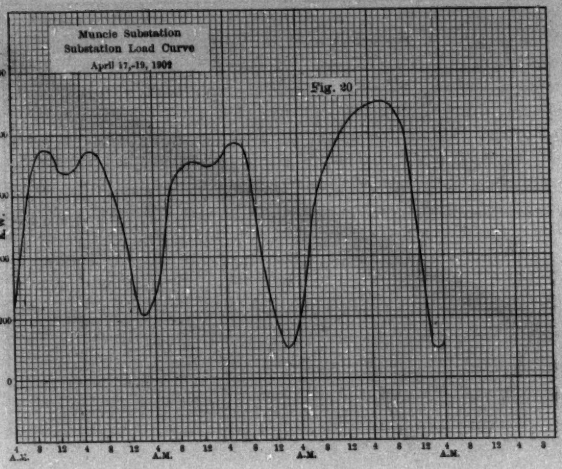

Muncie Substation
Substation Load Curve
April 17,-19, 1902
K.W.
1000
800
600
400
200
0
A.M.
A.M.
A.M.
A.M.

Fig. 20

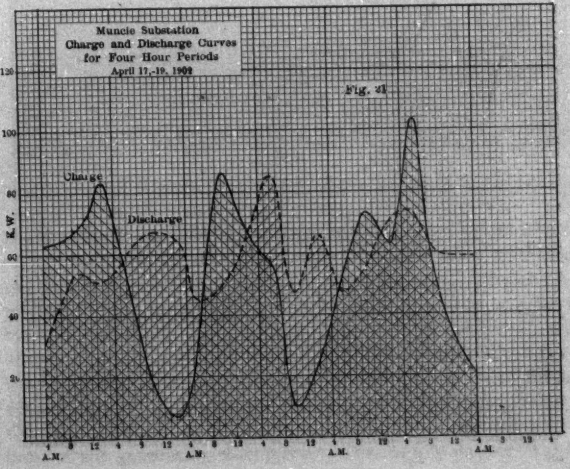

Muncie Substation
Charge and Discharge Curves
for Four Hour Periods
April 17,-19, 1902
Charge
Discharge
K.W.
120
100
80
60
40
20
A.M.
A.M.
A.M.
A.M.

Fig. 21

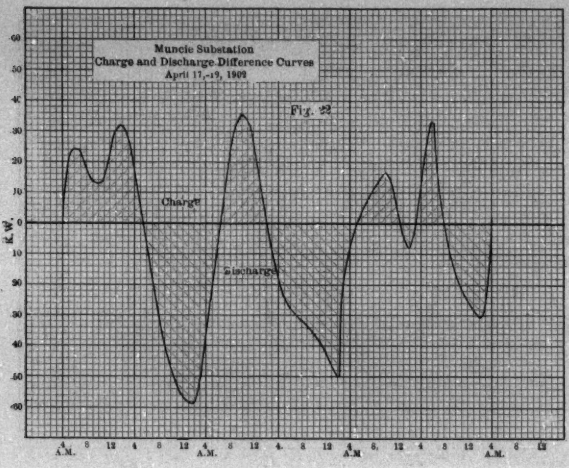

Muncie Substation
Charge and Discharge Difference Curves
April 17,-19, 1902
Charge
Discharge
K.W.
A.M.

Fig. 22.

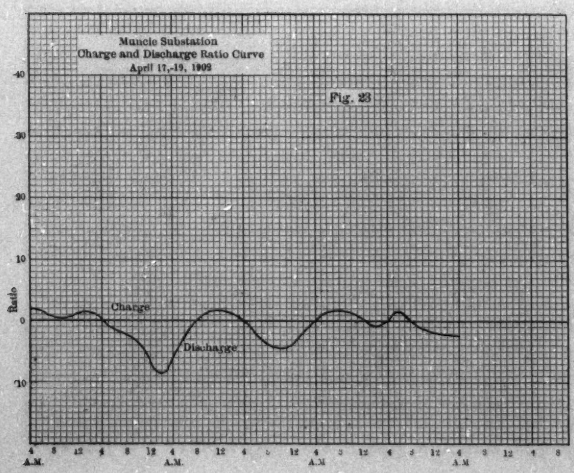
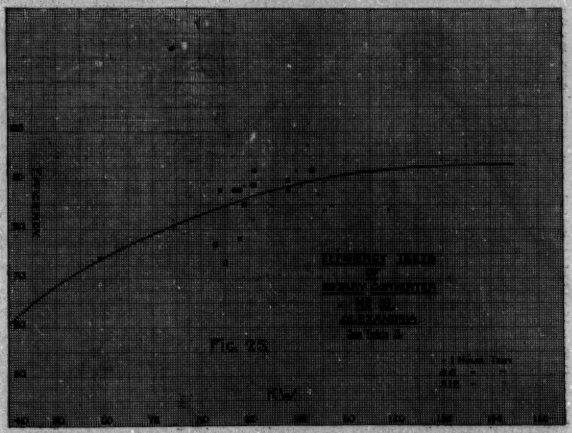

Muncie Substation
Charge and Discharge Ratio Curve
April 17,-19, 1902
Charge
Discharge
Ratio
A.M.

Fig. 23.

the highest discharge performance, as during the four hours between 12 midnight and 4 A. M. on April 19th, it developed 39 per cent. of its discharge capacity. The Marion, Anderson and Muncie batteries never developed more than 28 per cent. of their discharge capacity over a 4-hour period, and at Daleville the discharge performance during a 4-hour period did not exceed 14 per cent. These figures all go to show that as gauged by the average demand on the substations, the batteries are amply large enough to take care of variations in the demands made on the substations by the trains. It is confidentally believed, however, as has already been pointed out in the discussion of the



special test on the storage battery at the Ingalls substation (see Figs. 2 and 3), the motors driving the booster armatures were not heavy enough to hold up to the momentary demands which rapid changes in the load bring upon the substations, assuming the booster field windings are correctly designed. Proper adjustment would undoubtedly cause the batteries to show a very much higher charge and discharge k.w. performance during the 4-hour intervals, and they would better serve to reduce the fluctuations reflected through the substations from the trains to the central station. A diminution in the fluctuations of the load on the central station at Anderson will in turn increase the economy of the generating machinery. This is a point to which

FIG. 24.

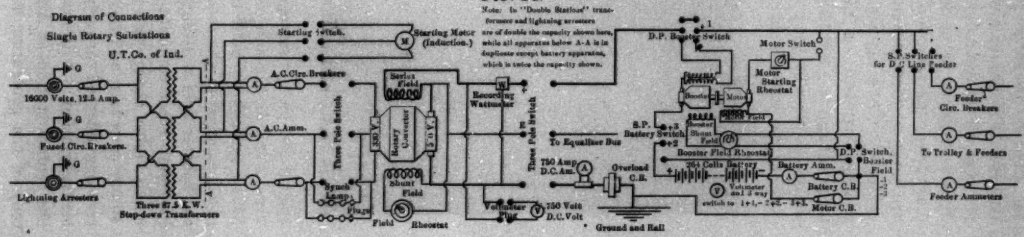


Diagram of Connections
Single Rotary Substations
U.T.Co. of Ind.
Starting Switch.
Starting Motor (Induction.)
A.C.Circ.Breakers
A.C.Amm.
16000 Volts, 12.5 Amp.
Fused Circ.Brakers.
Lightning Arresters
Three 37.5 K.W. Step-down Transformers
Three Pole Switch
Series Field
Rotary Converter
Shunt Field
Brush Lifting Magnet
Field Rheostat
Recording Wattmeter
Voltmeter
750 Volt D.C.Volt
Ground and Rail
Note: In "Double Station" transformer and lightning arresters are of double the capacity shown here, while all apparatus below A-A is in duplicate except battery apparatus, which is twice the capacity shown.
D.P. Battery Switch
Motor Switch
Motor Starting Rheostat
Booster
Motor
Booster Field
Booster Field Rheostat
S.P. Battery Switch
To Equalizer Bus
750 Amp. D.C.Amm.
Overload C.B.
56 Cells Battery
Battery Amm.
Battery C.B.
Motor C.B.
D.P. Switch, Booster Field
Switches for D.P. Line Feeder
Feeder Circ. Breakers
To Trolley & Feeders
Feeder Ammeters

FIG. 26.

attention should be given in laying out substations for work of this character, and it is one to which it is believed sufficient attention has not heretofore been directed.

The average commercial performance shown by the batteries during the three days of the test turns out to be 74 per cent. for the Marion battery, 88 per cent. for the Ingalls, 96 per cent. for the Anderson battery, 76 for the Daleville and 112 per cent. for the Muncie battery. Taking the ratio of the total discharge of all of the batteries to the total charge of all the batteries in these five substations, we obtain an aggregate efficiency of 95 per cent. for the batteries in the substation; or, if we average the efficiency values as obtained for the five substations, we get 89 per cent. as the average efficiency of the batteries during this time. These values are high, and yet they continue so for relatively long periods without any special indications of deterioration in the batteries. The batteries were left entirely in charge of the station attendants, and no effort was made at any time to in any way modify the usual performances. The tests indicate that these high efficiencies have been maintained, owing to the fact that only a slight tax has been made upon the capacity of the batteries by the service to which they are commonly subjected. Of course, the continuation of this kind of service indefinitely would in time make itself felt and cause deterioration in the batteries, a condition indicated by marked changes in the density of the electrolyte and rectified by a special charge being given to the battery at relatively long intervals to bring it back to normal condition. Over the system tested it is the practice to give the batteries a special charge on Sunday morning, thus bringing them back to good normal condition once every seven days. At this time the voltage and density of the electrolyte of each cell is taken and made of permanent record.

Special Instantaneous Demand Test.

It was possible during the test to make an exact instantaneous record of the current fluctuations occurring at the Anderson substation on March 19th by the following method: A strip of paper was fastened on a tin holder placed in front of the needle of a millivoltmeter and bent to conform to the path traced by the tip of the millivoltmeter needle. The tin holder was then lowered at a uniform rate in front of the voltmeter needle by a clockwork mechanism. The actual record was made on the paper by a continuous induction coil spark from the end of the needle to the

tin back of the paper. Deflections of the millivoltmeter were brought about by placing the instrument in shunt with a sufficient length of the bus-bar to give a considerable deflection. With the apparatus it was possible to obtain records of only twenty minutes duration; and, of course, curves could not be taken at the same time of both the rotary load and line load, as was the case in the Ingalls substation test, the results of which are shown in Figs. 2 and 3; but the instantaneous curves *were* taken under similar conditions of loading.

The upper half of Fig. 24 shows the variation in the demand made upon the Alexandria substation by the interurban cars; this record extends from 4.10 to 4.30 on the afternoon of March 19th. The maximum fluctuation in the load at any given time occurred just after 4.21 P. M., when there was an almost instantaneous demand of 500 amps., the load going from 200 to 700 amps. *instantly*, as nearly as it is possible to read the record.

The instrument was connected to the rotary bus-bar from 4.50 to 5.00 P. M. on the same day. There is no reason to believe that the demand upon the station during this time was very different from the demand upon the station during the time that the instrument was connected to register the line fluctuations. Accordingly, it would seem that on the afternoon in question the substation at Alexandria was working much more efficiently as an equalizer than was the battery at the Ingalls substation at the time the records were made which are recorded in Fig. 3. Owing to an unfortunate accident to the millivoltmeter is was impossible to obtain other instantaneous records than those presented, and, therefore, no estimate can be made of the exact efficiency of equalization of the Alexandria battery. Presumably, however, it is higher than that developed at the Ingalls substation, since the average load shown in the curves of Fig. 24 in both cases runs not far from 350 amps.; and while the upper curve is extremely irregular, the lower curve is comparatively uniform.

The maximum one-hour discharge rate of the Alexandria battery is 320 amps. The curves of Fig. 4 show that the demand on the batteries and rotaries together exceeded this discharge rate about once in every thirty seconds, with periods of very light load between. How much of these peaks the battery actually took is not possible to say, presumably, however, its maximum discharge rate for one hour of 320 amps. was frequently exceeded.

The authors desire to acknowledge their indebtedness to

A. S. Richey, Electrical Engineer of the Union Traction Co., S. Hollingsworth and G. P. Dinsmore for assistance which made the carrying out of these tests possible. Mr. Hollingsworth and Mr. Dinsmore were in immediate charge of the observers who took all readings at the various substations, and to their painstaking care is due the accuracy of the work.

TABLE I.

SUBSTATION ROTARY OUTPUT.
K.W.H.

Station.	April 17	April 18.	April 19.	Total.
Lawrence	1791	1780	1780	5351
Ingalls	1825	1742	1881	5448
Anderson	4400	4340	4827	13567
Daleville	1670	1690	1706	5066
Muncie	3406	3210	3658	10274
Alexandria	3235	2550	2945	8730
Fairmount	1440	1508	2050	4998
Marion	5330	5865	8040	19235
Elwood	1860	1825	1970	5655
Total	24957	24510	28857	78324

TABLE II.

EFFICIENCY OF HIGH TENSION LINES, TRANSFORMERS AND ROTARIES.

Date.	A.C. Output* K.W.H.	D.C. Output† K.W.H.	Efficiency.
April 17	28,000	20,557	73.3
April 18	27,270	20,170	73.9
April 19	32,750	24,030	73.3
Total	88,020	64,757	73.5

*This column is the total output of the Anderson generators as given by the recording wattmeter on the load panel, less the Anderson rotary input, obtained by dividing the Anderson rotary output by the efficiency of the rotaries—89%.

†This column is the sum of all the readings of the rotary wattmeters, less the output of the Anderson rotaries, as these were fed directly from the bus bars, through auto-transformers and not through the high tension lines.

TABLE III.

RESULTS OF EFFICIENCY TEST, ROTARY No. 19.

12 Hour Test.			6 Hour Test.		
Average Load K.W.	Per Cent. Load.	Efficiency.	Average Load K.W.	Per Cent. Load.	Efficiency.
84	33.6	88	88	35.2	88
88	35.2	88	91	36.5	92
98	39.3	88	87	34.9	88
98	39.3	90	88	35.2	88
73	29.2	85	91	36.5	89
78	31.2	88	103	41.2	92
Average.....	.....	87.8	77	30.8	83
			85	34.0	89
			59	23.6	74
			Average	.....	87

TABLE III. (*Continued.*)

1 Hour Test.

Average Load K.W.	Per Cent. Load.	Efficiency.
60.0	24.0	81.0
74.4	29.8	80.0
74.4	29.8	82.0
76.4	30.5	79.0
78.0	31.2	94.0
86.4	34.6	95.0
89.0	35.5	89.0
91.2	36.0	82.0
99.6	39.8	92.0
100.8	40.5	89.0
102.0	40.8	97.0
104.4	41.7	87.0
105.6	42.1	84.0
105.6	42.1	90.0
106.8	42.9	85.0
118.8	47.5	84.0
133.4	53.3	94.0
135.4	54.0	97.0
Average 96.8	38.7	88.3

TABLE IV.

EFFICIENCY OF HIGH-TENSION LINES, TRANSFORMERS AND ROTARIES.

Quantity.	April 17.	April 18.	April 19.	Total.
Step-up trans. input.....	28,000	27,270	32,750	88,020
Step-up trans. efficiency.....	95	95	95	95
High-tension line input	26,600	25,900	31,070	83,570
High-tension line efficiency.....	93.0	92.0	92.7	92.9
Step-down trans. input.....	24,700	23,800	28,750	77,450
Step-down trans. efficiency	95.0	95.0	95.0	95.0
Rotary input	23,500	22,600	27,360	73,560
Rotary efficiency	88.0	88.0	88.0	88.0
Rotary output.....	20,657	19,770	24,030	64,457
TOTAL EFFICIENCY	73.3	73.9	73.3	73.5

TABLE V.

EFFICIENCY OF D.C. DISTRIBUTION.

ANDERSON-MUNCIE DIVISION.

Input to Line.

	April 17.	April 18.	April 19.	Total.
Anderson Inter. East	73.2	3.0	75.5	181.7
Daleville Rotary	1670.0	1681.3	1706.0	5057.3
Daleville Bat. Dis	67.0	89.4	77.5	233.9
Daleville Bat. Ch	75.8	107.1	112.0	294.9
Muncie Inter. West	268.5	268.8	355.0	892.3
Total	2002.9	1935.4	2102.0	6092.3
INPUT TO CARS.				
Regular cars	1448.2	1435.3	1465.0	4348.5
Special cars	56.9	103.6	173.0	333.5
Total	1505.1	1538.9	1638.0	4682.0
Efficiency	78.2	79.5	77.9	77.7

ANDERSON-INDIANAPOLIS DIVISION.

INPUT TO LINE.

	April 17.	April 18.	April 19.	Total.
Lawrence Rotary	1780.0	1784.88	2001.0	5565.88
Lawrence Bat. Dis	122.6	101.03	67.1	290.73
Lawrence Bat. Ch	115.2	131.79	147.0	393.99
Ingalls Rotary	1830.0	1703.59	1880.0	5413.59
Ingalls Bat. Dis	98.2	180.15	147.0	425.35
Ingalls Bat. Ch	156.0	140.26	182.0	478.26
Anderson Int. W.	714.0	735.60	1030.0	2479.6
Total	4273.6	4233.2	4796.0	13302.8
INPUT TO CARS.				
Regular cars	3096.8	3060.6	3340.4	9497.8
Special cars	42.4	79.1	26.3	147.8
Total	3137.2	3139.7	3366.7	9643.6
Efficiency	73.5	74.1	70.4	71.3

TABLE VI

AVERAGE D.C. LINE EFFICIENCY.

Division.	April 17.	April 18.	April 19.	Total.
Anderson-Muncie	78.2	79.5	77.9	78.5
Anderson-Indianapolis	73.5	74.1	70.9	72.5

TABLE VI.—Continued.

AVERAGE D. C. LINE EFFICIENCY.

Date.	Total Input to Line. K.W.H.	Total Input to Cars. K.W.H.	Efficiency, Indianapolis. Muncie.
April 17	6197.3	4644.3	75.0%
April 18	6165.7	4678.6	76.0
April 19	6898.0	5004.7	73.0%
Total	19261.0	14327.6	74.5%

TABLE VII.

SUBSTATION BATTERY OUTPUT.

	April 17 K.W.H.	April 18 K.W.H.	April 19 K.W.H.	Total K.W.H.	Three day Efficiency.
Lawrence Charge	115.2	131.8	147.0	394.0	74%
Lawrence Discharge	123.6	101.0	67.1	290.7	
Ingalls Charge	156.0	140.3	182.0	482.3	88%
Ingalls Discharge	98.0	180.2	147.0	425.2	
Anderson Charge	477.4	423.7	503.2	1404.3	96%
Anderson Discharge	364.5	446.7	537.9	1348.0	
Daleville Charge	100.3	107.1	112.0	319.4	76%
Daleville Discharge	75.0	89.1	77.5	241.6	
Muncie Charge	293.0	282.0	367.0	942.0	112%
Muncie Discharge	332.0	359.0	365.0	1056.0	
Total Charge				3541.0	95%
Total Discharge				3362.0	
Average					89%

TABLE VIII.

CAPACITY OF SUBSTATION BATTERIES.

Battery in Substation at	Battery Discharge Rate in Amperes for			Battery Capacity in K.W.H. when Discharged in		
	1 Hr.	4 Hrs.	8 Hrs.	1 Hr.	4 Hrs.	8 Hrs.
Anderson	400	160	100	211	337	422
Muncie	320	128	80	169	271	338
Lawrence	160	64	40	85	135	169

Batteries at Alexandria and Marion have same capacity as battery at Muncie.
Batteries at Ingalls, Daleville, Fairmount and Elwood have same capacity as battery at Lawrence.

TABLE IX.

PER CENT. OF BATTERY CAPACITY DEVELOPED.

	4 Hour Discharge Rating.	Max. Discharge in 4 Hrs. K.W.H.		Per Cent. of 4 Hour Discharge Capacity Developed.	
	K.W.H.	Total.	Dif.	Total.	Dif.
Lawrence	135.0	33.0	30.0	24.4	22.2
Ingalls	135.0	52.0	50.0	38.5	37.0
Anderson.....	337.0	111.0	89.0	32.9	26.4
Daleville.....	135.0	24.0	18 0	17.7	21.7
Muncie.....	271.0	85.0	80.0	31.3	

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

SOME NOTES ON THE OPERATION OF RAILWAY MOTORS IN SERVICE.

BY CLARENCE RENSHAW.

Part I.

The Equivalent Effect of Service Loads.

A combination of the speed-time and input curves indicates in general the performance of an equipment of railway motors with reference to its external characteristics. Judged from these curves only, a given equipment may be perfectly capable of performing a desired service satisfactorily and yet it may be entirely unsuited for the work, so that further information is necessary. The three factors which limit the safe loads for a given motor are: First, its commutation; secondly, its mechanical strength and, thirdly, the temperature rise of the windings. The capacity in regard to the first and second items is usually very much greater than that with reference to the third. As far as commutation and mechanical strength are concerned, a railway motor as a rule could operate continuously with loads which would completely destroy the windings in a single day or less. It is usually the temperature rise which limits the capacity. Owing to these facts, railway motors are particularly subject to misuse. Chosen with reference to their apparent capacity only and without due regard to the loads which they may carry safely, such motors are liable to be applied to work for which they are not suited. The general tendency in such cases is to choose equipments that are

too small. It is only in comparatively recent years that the amount of power necessary for operating cars, and the tremendous effect on it of changing such items as the weight of car, speed and number of stops, have begun to be known accurately. The first railway motors used (based in capacity on the number of horses required for a horse car) were none too large for the duty required of them; and in the case of each new line of railway, engineers have some times hesitated to advise, and owners have usually hesitated to buy, motors larger than those in use on similar existing lines, merely because their cars were to be slightly heavier and the speed a little greater.

When new motors are first installed, the effect of overloads will usually not be apparent at once. The damage done by abnormal temperatures is, as a rule, not instantaneous but gradual. Owing to the inaccessibility of a railway motor when mounted for service, the temperature which it attains is not likely to be noticed unless it is particularly sought for. It is only when a motor has been overloaded sufficiently long to roast coils or make other repairs necessary that trouble is suspected. Even then in seeking the cause of the trouble, overloading pure and simple is the last thing to be thought of; the fault is much more likely to be attributed to defective material or construction. Thus it will be seen that the temperature problem is an important one. A due consideration of the loads which they may safely carry is thus essential to the proper selection of railway motors for specific service.

The necessity for a simple test by means of which engineers in charge of railway systems can determine the loads on motors and whether these loads are within the capacity of the motor or not is obvious.

The predetermination of the exact temperature rise of the different parts of a railway motor, operating at given loads and under any given service conditions, is a difficult and complex problem. So difficult and so complex indeed is this problem, that it is impracticable, if not impossible, for manufacturers of railway motors to furnish, for general circulation and in a form which can be readily uuderstood and used by the average engineer, the data necessary for its solution for each type of their product. For general use, however, such detail is unnecessary. The problem, from the standpoint of the user, as a rule, is not, what will be the temperature of the field, or of the armature of such a motor under certain service conditions, but rather, will the temperature of the motor be such as to insure normal life and reasonable re-

pairs. In other words, are the loads carried by the motor within its capacity. Information leading to the solution of this problem can readily be furnished, in brief form, easily understood, readily used and generally applicable either to the predetermination, or to the final confirmation, of the fitness of a motor for its work.

Service Loads.

The daily operation of a car over any particular line or route consists of short runs between various intermediate points along the road. These runs may vary considerably in character; some may be up grade, others down grade; some may be short, others may be long; some may be made at slow speed and others at a higher speed, and runs between the same two consecutive stopping points may on different trips be made in different ways.

For any given type of car on a given road the average all day load, day in and day out, will be remarkably uniform, especially in view of the large number of circumstances which might cause variance. In any given case an average run between stops; that is, an average cycle of operation, can usually be picked out, which will in general fairly approximate the entire service.

Such an average run for a car of the type ordinarily used in combined city and suburban service, is shown in Fig. 1 and for a car in high-speed interurban service, in Fig. 2. In city service alone, the curves would be similar to those of Fig. 1, except that power would be cut off sooner and the length of run would be shorter. Each of these figures shows a complete operating cycle, including the speed, line voltage and current consumption of the car, as well as the current used by each motor and the voltage at its terminals. The current used by each motor is not merely one-half of that used by the car, since, when the motors are in series, the car current and the motor current are identical. Both figures are actual cases taken from tests.

It will be seen from Fig. 1 that the load carried by each motor varies from a maximum input of 95 amperes (or about four-thirds of the one hour rating of the motor) to 23 amperes (or about one-third of this rating). The voltage at the terminals of each motor varies from 80 volts to the rated voltage of 500. Moreover, the load varies through this entire range in less than three-fourths of a minute. For the next one-fourth of a minute, approximately, while the car is coasting and being stopped, the motors carry no load at all and this entire cycle is repeated a little less often than once every minute.

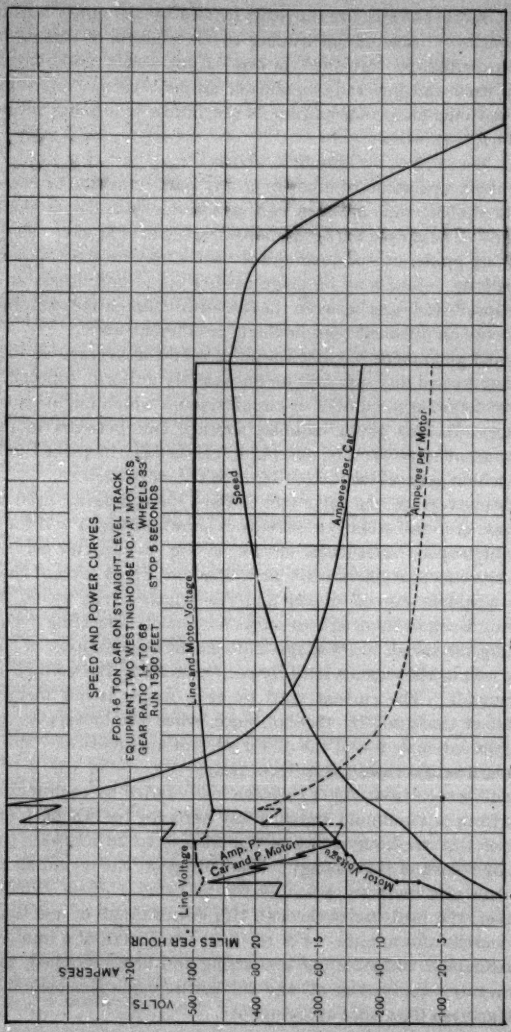

SPEED AND POWER CURVES
FOR 16 TON CAR ON STRAIGHT LEVEL TRACK
EQUIPMENT, TWO WESTINGHOUSE NO. "A" MOTORS
GEAR RATIO 14 TO 68
RUN 1500 FEET
WHEELS 33"
STOP 5 SECONDS
Line and Motor Voltage
Speed
Amperes per Car
Amperes per Motor
Line Voltage
Amp. P. Car and P. Motor
Motor Voltage
VOLTS
AMPERES
MILES PER HOUR
SECONDS

Fig. 1.

In the service shown by Fig. 2, the conditions are more uniform. The maximum current is 280 amperes per motor and the minimum, 77½ amperes. The motor voltage varies from 30 volts to 545 volts. For over half of the entire cycle, however, the current and voltage are quite uniform. The length of the cycle in this case is six minutes and twenty seconds. This is considerably longer than the average cycle on most interurban roads.

Losses.

When a motor is carrying any load, certain copper and iron losses take place in it, which depend upon the load. It is these losses, which appear as heat, that tend to raise the temperature of the windings. Thus a loss of three watts (neglecting radiation) will raise the temperature of one pound of copper approximately 1° C. per mintue or of one pound of iron approximately .8° C. per minute. The copper loss depends upon the current only, and is proportional to its square, but the iron, or core loss, depends upon both the current and the voltage and does not follow any simple law. The iron loss in the motors in question, when carrying any given current at any given voltage, is shown in Figs. 3 and 4. Its dependence on both current and voltage may be seen in Fig. 3, from the fact that 20 amperes at 500 volts, produces the same loss as 105 amperes at 305 volts.

The losses which take place in each motor at every instant during the cycle shown in Fig. 1, were calculated from Fig. 3 and from the resistance of the motor and are shown in Fig. 5. Those which occur in each motor in Fig. 2 were calculated in like manner and are shown in Fig. 6. Owing to the great mass of metal in its frame, a motor has a considerable amount of heat storage-capacity. Instead of only a few hundred pounds of copper in the windings to be acted on, the temperature of the frame must also be raised; when cooling the entire mass must cool off simultaneously. That is, when the temperature of the windings is rising, that the frame must also rise, and similarly when falling. The actual temperatures of the different parts may, of course, be widely different. Owing to this action, the temperature rise of the windings of the motor does not fluctuate in accordance with the instantaneous losses but rises at a fairly uniform rate depending on their average value.

Equivalent Loads.

The important factor as regards the effect of the service loads on the motors, provided that the maximum loads are within the

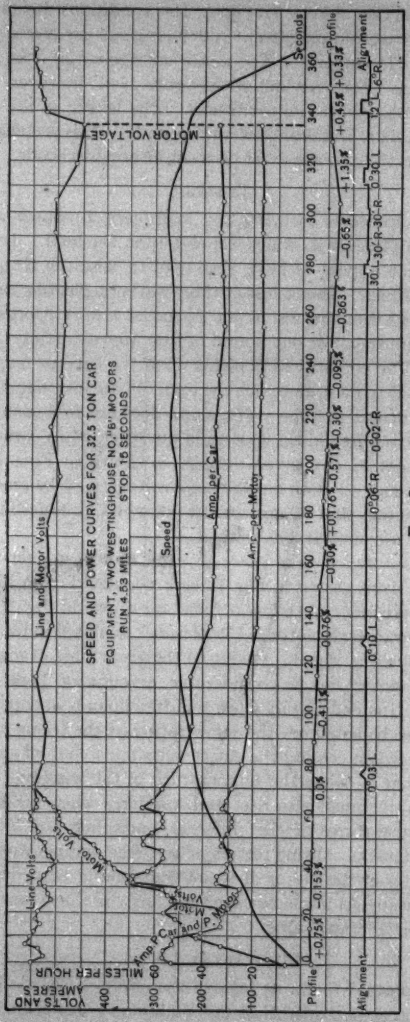

SPEED AND POWER CURVES FOR 32.5 TON CAR
EQUIPMENT, TWO WESTINGHOUSE NO. "B" MOTORS
RUN 4.53 MILES STOP 16 SECONDS
Line and Motor Volts
Speed
Amp. per Car
Amp. per Motor
MOTOR VOLTAGE
Seconds
Profile
Alignment
VOLTS AND AMPERES
MILES PER HOUR
Line Volts
Motor Volts
Amp. per Car
Amp. per Motor
Profile
Alignment

FIG. 2.

proper limits, is thus the average value of the losses, averaged of course over the entire time of the cycle; that is, in Fig. 1 for 66 seconds and in Fig. 2 for 380 seconds. It is evident that the average copper loss in any case is equal to that which would be produced by the continuous application of a current equal in value to the

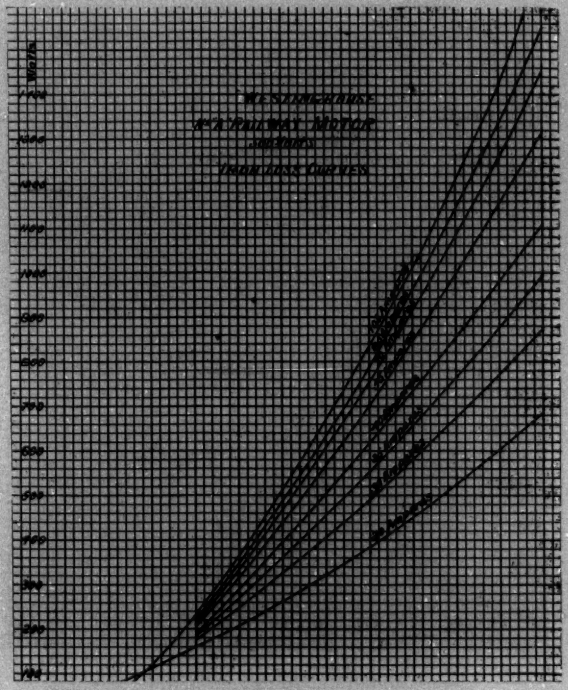


FIG. 3.

root mean square of the service currents. For instance, in Fig. 5 the average copper loss is 750 watts. The root mean square current per motor is 34 amperes and the resistance .65 ohms, which of course gives the same result. Thus the variable service

currents shown in Fig. 1 are equivalent—with regard to the heating effect of the copper loss produced by them—to a current of 34 amperes per motor, applied continuously.

The average iron loss produced by the service loads of Fg. 1, as noted in Fig. 5, is 400 watts. Referring to Fig. 3 it will be

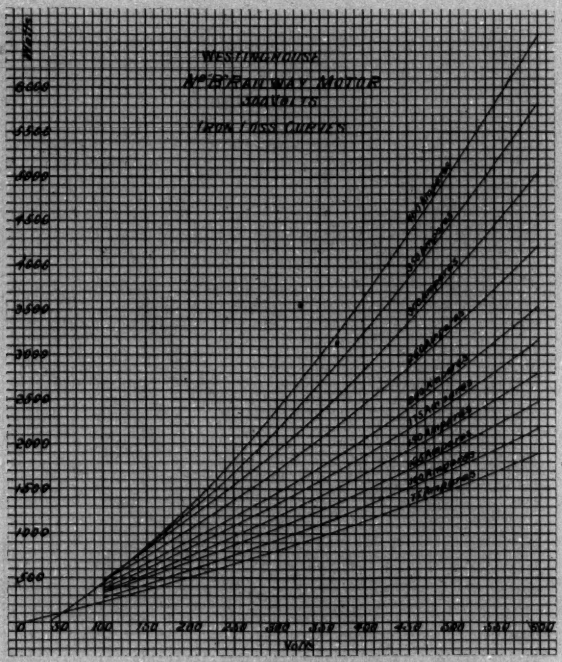


FIG. 4

seen that a current of 34 amperes, *i.e.*, the root mean square current, applied to each motor at 325 volts will produce this same iron loss. Thus, if this current and voltage is applied to the motor for the entire cycle, the average losses in the motors—

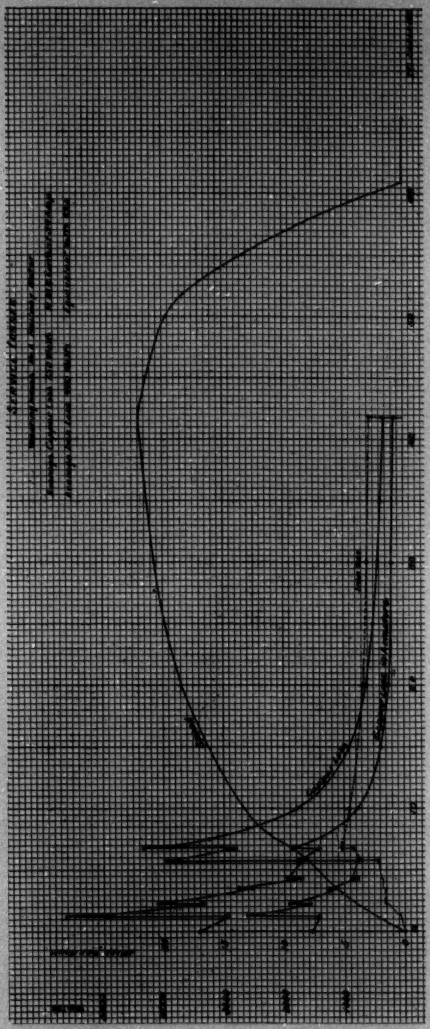


FIG. 5.

both copper loss and iron loss—will have the same value and the same distribution as the losses due to the service loads. This voltage may be called the " equivalent " voltage of the service. In the service shown in Fig. 2, the relative values of the losses are somewhat different. In this case the average copper loss is only 960 watts while the average iron loss is 1410 watts. The root mean square current is 107 amperes and referring to Fig. 4 it will be seen that the equivalent voltage is 420. As regards the production of heat in the motors, then, the service shown in Fig. 1 may be described as equivalent to a continuous current of 34 amperes at 325 volts and that shown in Fig. 2 as equivalent to 107 amperes at 420 volts, and any railway service may be similarly described.

This method of equating the service loads on a railway motor to simple and intelligible terms was devised by Mr. N. W. Storer of Pittsburg, and gives a convenient way of expressing the service capacity of railway motors in a usable manner.

The limiting capacity of any type of motor may be readily expressed by the manufacturer in terms of the current (root mean square) which it will carry continuously at various voltages (equivalent voltage) with a safe rise in temperature. In choosing a motor for a given service, the root mean square current and equivalent voltage can be calculated from the speed-time curves and a comparison of these results with the values allowable for the motor in question will determine its fitness. Where motors are already installed, the continuous equivalent of the service can be found by means of comparatively simple tests and the relation of the actual loads carried by the motors, to their safe capacity, thus determined.

It has doubtless been noted that the equivalent voltages in the widely different service shown by Fig. 1 and Fig. 2 differ by less than 100 volts. If the run in Fig. 1 had been shorter, the equivalent voltage would have been somewhat lower, and if that in Fig. 2 had been longer (it is already longer than the average for perhaps nine-tenths of the interubran roads now in operation) the equivalent voltage in it would probably have been somewhat greater. It has been found that where the equivalent voltage is less than 300, a reduction of voltage, with the same current, makes but little difference in the temperature attained. Even when the equivalent voltage is changed from 300 to 400 volts only a comparatively slight reduction in current is necessary in order to

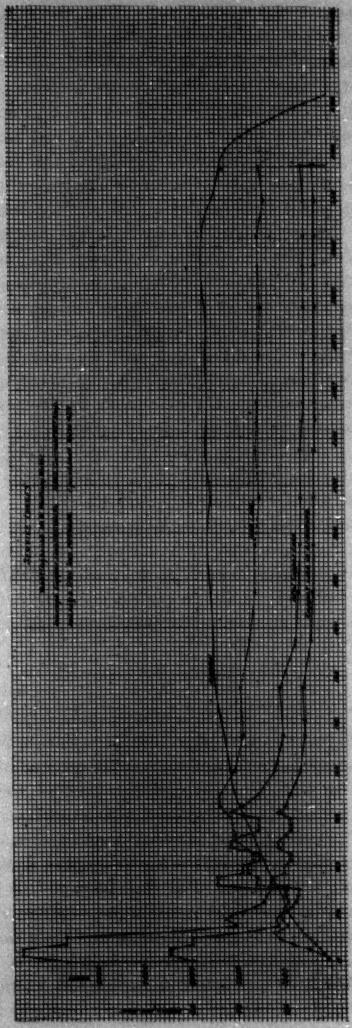


FIG. 6.

maintain the same temperature rise. Thus the capacity need be stated at only one or two different voltages.

In many cases where tests or calculations are made to determine the approximate service loads on a motor, the average voltage at the motor terminals is a sufficient indication of the iron losses and the equivalent voltage need not be determined. In Fig. 2, for instance, the average voltage at the motor terminals is 418, which is very close to the equivalent voltage. In Fig. 1 the average motor voltage is 290 volts, which is about 90 per cent. of the equivalent voltage; but it has already been pointed out that when the equivalent voltage is as low as this, any further reduction has but little effect on the temperature.

An ammeter in the circuit of one motor and a voltmeter at the terminals of the same motor, read at suitable intervals during a typical round trip over a given route, will thus give sufficient data for determining the loads which a motor is carrying in service. From the current readings, the root mean square current can be found and from the voltage readings, the average, or the equivalent voltage. It will be seen from Figs. 5 and 6 that the starting current is a most important factor in determining the copper loss, hence it is essential to get an accurate idea of this. On account of the rapid variations of the current while the car is starting and the short duration of the starting currents, it will be seen from Figs. 1 and 2 that readings should be taken at very close intervals, preferably at intervals of five seconds, or less, in order that the large currents used in starting may be duly represented in the results.

Part II.

Tests on an Electric Car in City Service.

The foregoing part of this paper has been devoted to a discussion of the average loads carried by railway motors in service and to methods of determining them, with a view to preventing the application of such motors to work for which they are not suitable. In the following, the results of a comprehensive series of tests on a car in exceptionally severe city service are presented, showing the actual variation of the loads in all day service. In these tests, the temperature of the field coils of one of the motors was measured in addition to the average loads and the general relation between average load and temperature may be seen. Complete details in regard to schedule speed, passengers carried, number and duration of stops, etc., were taken also and the tests afford

data on a number of minor subjects which have a bearing on the choice of motors for city service.

The tests in which these results were obtained were made recently, under the direction of the writer, on a car of the Pittsburg Railways Company. The car was of the single truck type approximately 30 feet long over all. The body was 20 feet long and had longitudinal seats for 28 people. The equipment consisted of two Westinghouse No. 62 motors with electric brakes of the disc type. The weight of the empty car complete with equipment but without load was approximately 12 tons. The motors were geared for a maximum speed on the level of approximately 26 m.p.h with 500 volts. The car was run in regular service, carrying passengers. Three observers were needed to take the necessary data. Two of these were located on the front platform with the motorman and the third on the rear platform with the conductor. The primary object of the tests was to study the temperature attained by the motors in all day service (particularly the temperature of the field coils). A complete record of all conditions was kept and from this a number of other interesting facts were obtained in addition to the temperature results.

Methods of Measurement.

It was desired to measure the temperature at frequent intervals, so that this necessarily had to be done without interfering with the operation of the car. The ordinary methods of temperature measurement by thermometer or by increase of resistance of the windings of the motor could thus not be used. The following plan was adopted. A small temperature coil consisting of 48 feet of No. 27 annealed iron wire was calibrated in an oil bath and an accurate comparison between its resistance and the temperature was obtained. This iron wire was then wound upon two thin wooden strips, and, during the process of winding a field coil for use on one of the motors, these two strips were placed in the interior of the coil, one on each side, about half-way between the center and the outside. Leads were brought out from this iron wire coil and measurements of its resistance which could thus be taken, gave the temperature of the interior of the field coil. The field coil which had been prepared in this way was placed on one of the motors of the car and the leads from the temperature coil brought to a portable Wheatstone bridge on the front platform. By the use of this arrangement the temperature

of the coils could be obtained at any time whether the car was running or standing still and whether the motors were using current or not. During the tests, measurements were made every four or five minutes. Before the field coil was placed on the motor, a test was made on it to determine the relation between the temperature as indicated by it and the resistance of the field. To obtain the temperature of the armature, it was proposed to measure its resistance during the short lay over at the end of each round trip made by the car. The lay over was so short, however, that this could be done only hurriedly, and frequently could not be done at all. In general, the results were not very satisfactory. As far as could be judged, however, the temperature of the armature was not materially different from that of the field.

In connection with the temperature of the field coil, it was desired to note the root mean square current producing this temperature. In order to avoid the great amount of labor which would have been necessary to calculate this quantity from the current for an entire day's run of nineteen or twenty hours, it was measured directly, as follows:

A street car wattmeter was connected in the field circuit of the motor so that it would measure the watthours lost in the field. In adapting the wattmeter for this purpose the large resistance which is ordinarily inserted in series with the armature of the meter when it is used on a 500 volt circuit was replaced by a smaller resistance suitable for the voltage drop across the field, with maximum current. The wattmeter was of course calibrated with this special resistance. When arranged in this way, the wattmeter measured the product of $I^2 R$ and T, where I is the current, R the resistance of the field coils and T the total time. The resistance of the iron wire temperature coil at any time, by reference to the comparative test previously made, showed the resistance of the field coil, and the average value of this resistance between any two times could thus easily be found. The time was noted with a watch and hence T and R could be eliminated from the measurement made by the wattmeter, leaving I^2, the square root of which was the quantity desired. In working up the test, the root mean square current was calculated in this manner for each single trip between terminals and also for each round trip. Previous tests over this same road had showed the average motor voltage to be about 175 volts and in the present tests this quantity was not measured. The average line voltage had been found to be about 450 volts.

The observer on the rear platform noted the number, duration and location of stops made by the car, the time of passing prominent points along the route and also the entrance or exit of each passenger.

Temperature Results.

The results of the temperature tests are shown by the curves in Figs. 7 and 8. These curves show also the root mean square current, the number of stops and the maximum and average number of passengers for each single trip. Five different runs were made with the car equipped as above, three over the Hamilton Avenue line (42,000 feet long, one way) and two over the Highland Avenue line (36,000 feet long, one way). For the first 25,000 feet, these two lines coincide. On the Hamilton Avenue line the car was run singly. On the Highland Avenue line a trailer was hauled for one trip in the morning and one trip in the afternoon. Fig. 7 shows the results of one of the tests on the Hamilton Avenue line and Fig. 8 of one on the Highland Avenue line.

Referring to Fig. 7, it will be seen that, starting at a temperature of 25½° C., or 13° C. above the temperature of the air, the temperature of the inside of the field coil rose gradually until at the end of eight hours it had reached a temperature of 74° C. During the next eight hours the temperature remained practically constant at this value (maximum rise, 64½° C.). During the following three hours, which were late in the evening, the air temperature decreased and the temperature of the field coil decreased with it, reaching a temperature of 70° C. at the end of the last regular trip. Measurements of the temperature were taken also at intervals of ten minutes while the car was standing idle during the night and these results are likewise shown in Fig. 7. The cooling of the motor was interrupted for a short time by the application of current in order to move the car from the yard into the car barn, and a hump in the curve shows the effect of this. It will be seen that after approximately four hours of idleness, at the end of which time the car was made ready to start out on the next day's service, the temperature had fallen from 70° C. to 32 °C., the latter point being a little over 20° above the temperature of the air. Thus ordinarily a motor never gets completely "cold." The curves shown in Fig. 7 were taken on the first day of a two days continuous test. On the second day the curves obtained were practically duplicates of those shown.

On the run on Highland Avenue, Fig. 8, the temperature of the field coil at starting was 18° C. or 5° above the atmosphere. The

addition of the trailer for its morning trip caused a much more rapid rise of the temperature than was the case in the run shown in Fig. 7 and a temperature of 60° C. was reached at the end of about three hours. After the removal of the trailer, the rise in temperature was more gradual. Had it not been for the addition of the trailer for its evening trip, the temperature of the field coil in this case would have remained constant at approximately 75°C. giving a rise approximately the same as in the other case. The addition of the trailer, however, caused a rapid rise to a temperature of 98½° C. When the trailer was again removed and the motor run once more at its normal rate, the temperature fell off gradually to 74° C., that is, a little less than its former temperature. It should be noted that the trailer was on for this afternoon trip only 1½ hours, while about 3 hours was required after its removal for the motors to cool off to the temperature at which they were before the addition of the trailer, and at which they would probably have remained had the trailer not been added. If the trailer had been left on for additional trips, it is evident that the temperature would have reached a much higher value. As the car was not put in service for an early run on the day following this test, the cooling curves could be continued for a longer time. It will be noted that the field coil cooled from a temperature of 71½° C. to a temperature of 25° C. (which latter point was a little over 12° C. above the atmosphere) in about 8 hours.

Load on Motors—Root Mean Square Current.

Referring to the root mean square current values shown on Fig. 7, it will be seen that these vary for a single trip, alternating in direction, from 39 to 51 amperes, or a little over 25 per cent. It will be seen that the values for the different up trips, however, and those for the different down trips are much closer together in each case than this. Comparing the root mean square currents on a basis of round trips instead of single trips, the variation for the different round trips on this all day run was only 42.5 amperes to 46 amperes, or less than 10 per cent. The average value of the root mean square current for the entire day's service was 43.6 amperes, so that the difference between this average and the extremes for the various round trips was very slight. The average all day values of the root mean square current for five different all-day runs, made on two different lines and made, respectively, on the 9th, 10th, 16th, 21st and 24th day of the

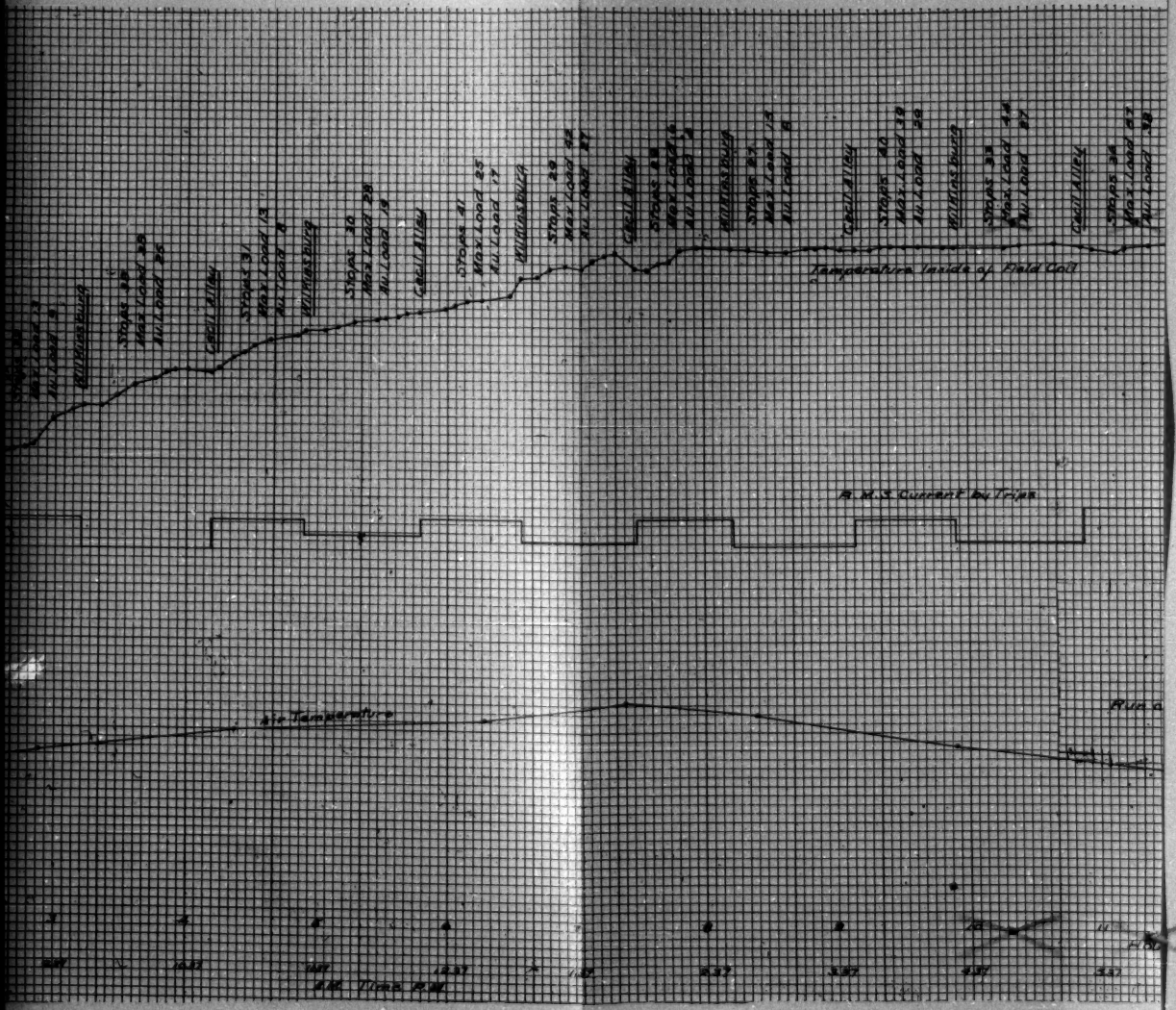

Temperature Inside of Field Coil
R. M. S. Current by Triax
Air Temperature

FIG. 7.—(Ren

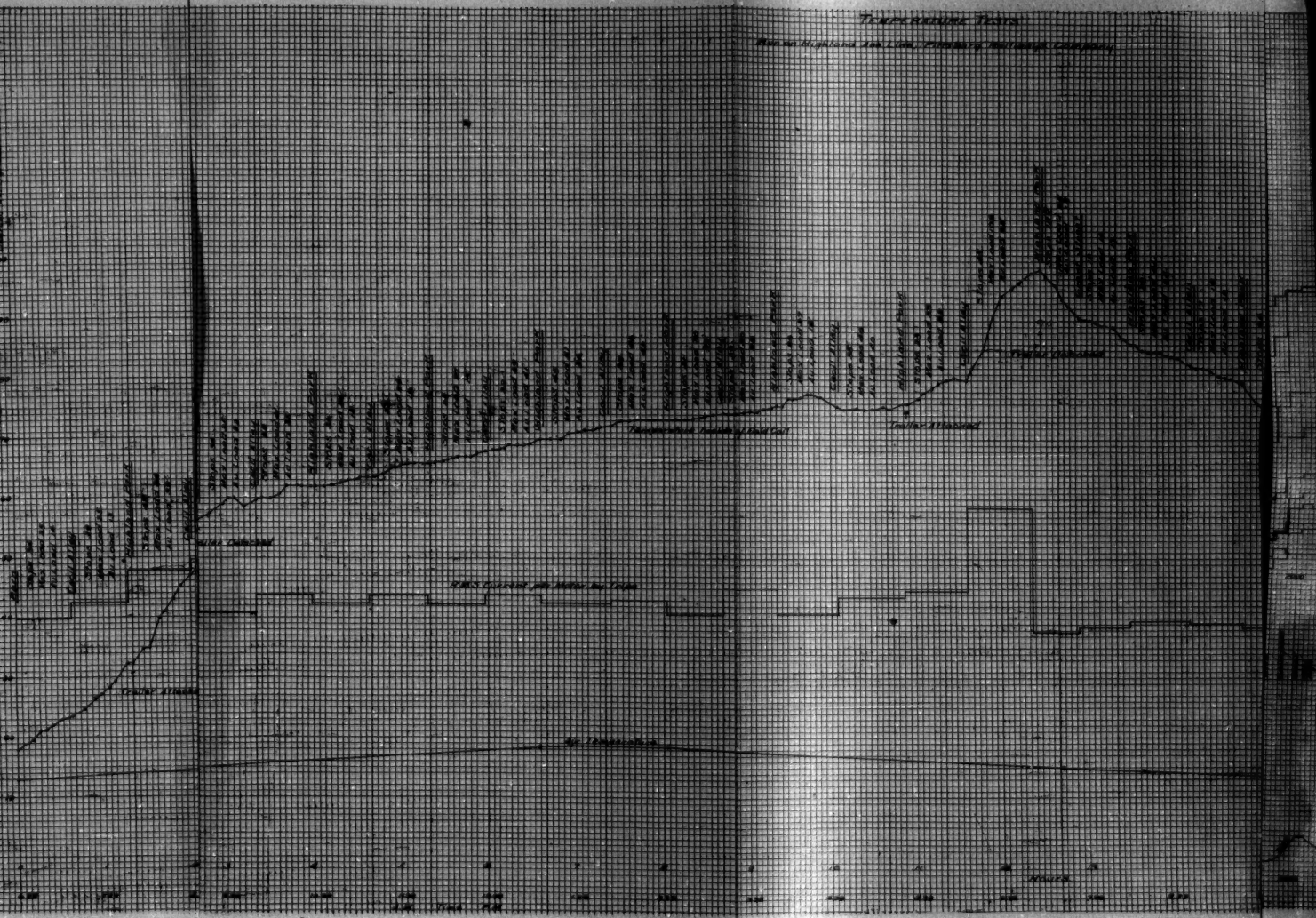


FIG. 8.—(Renshaw.)

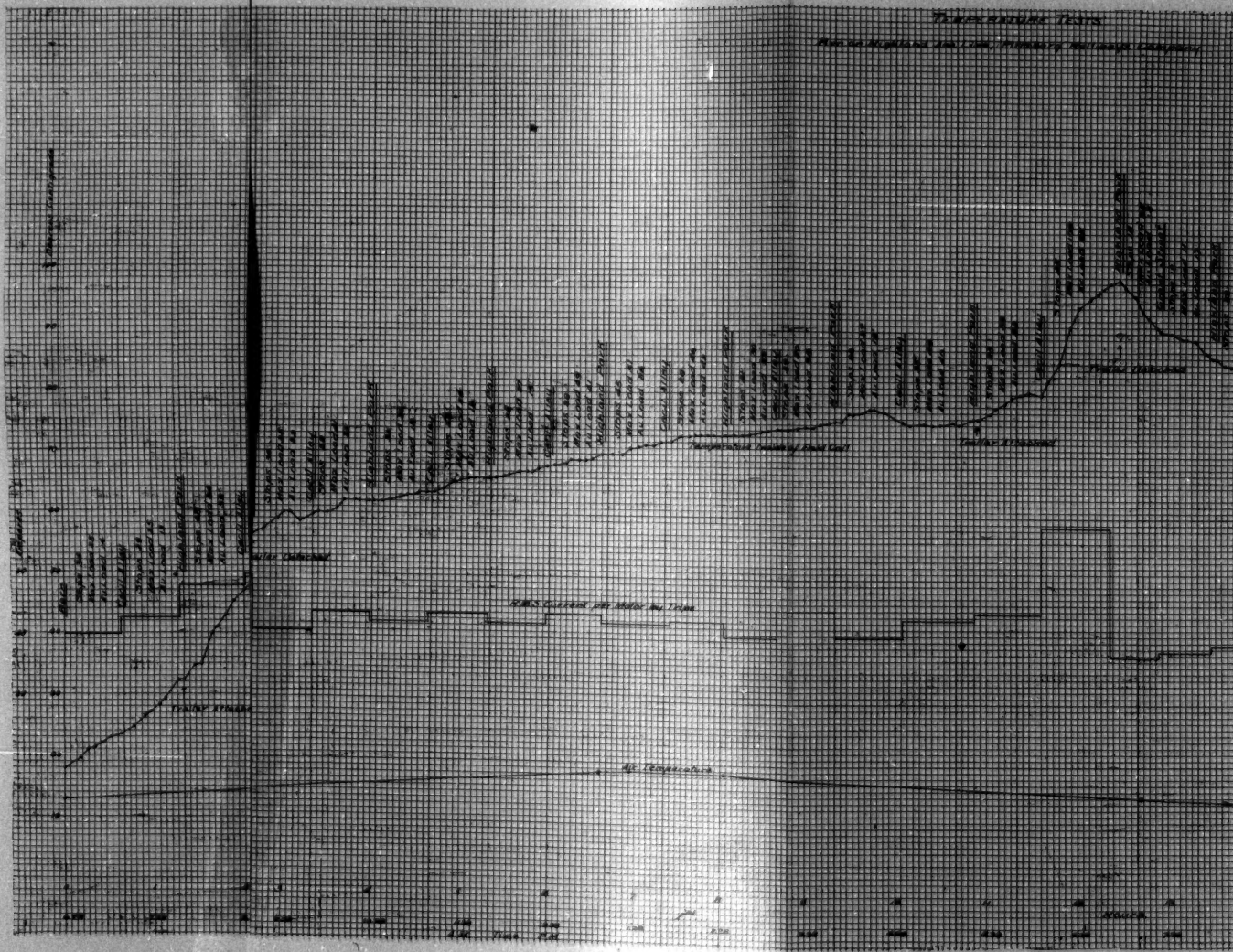
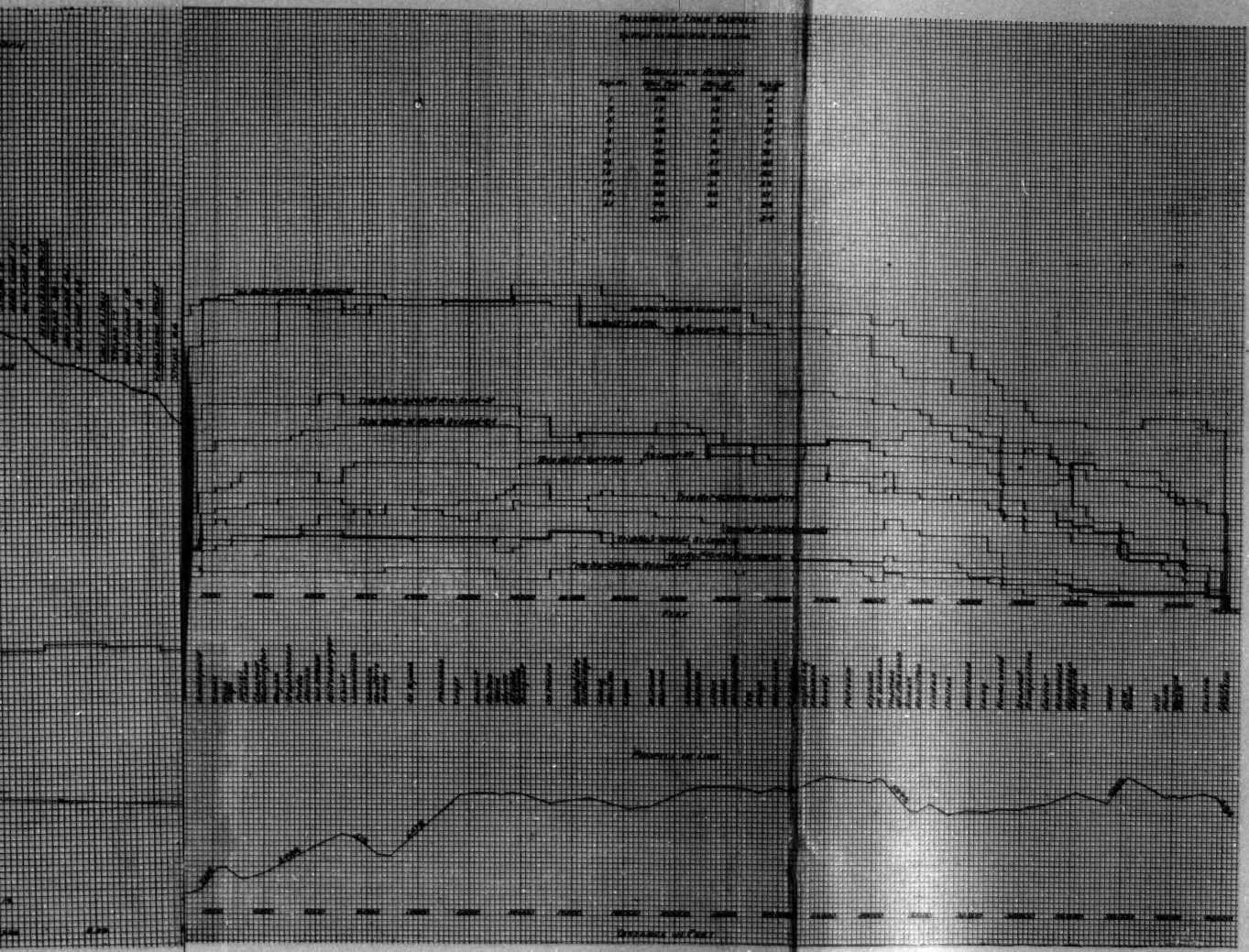
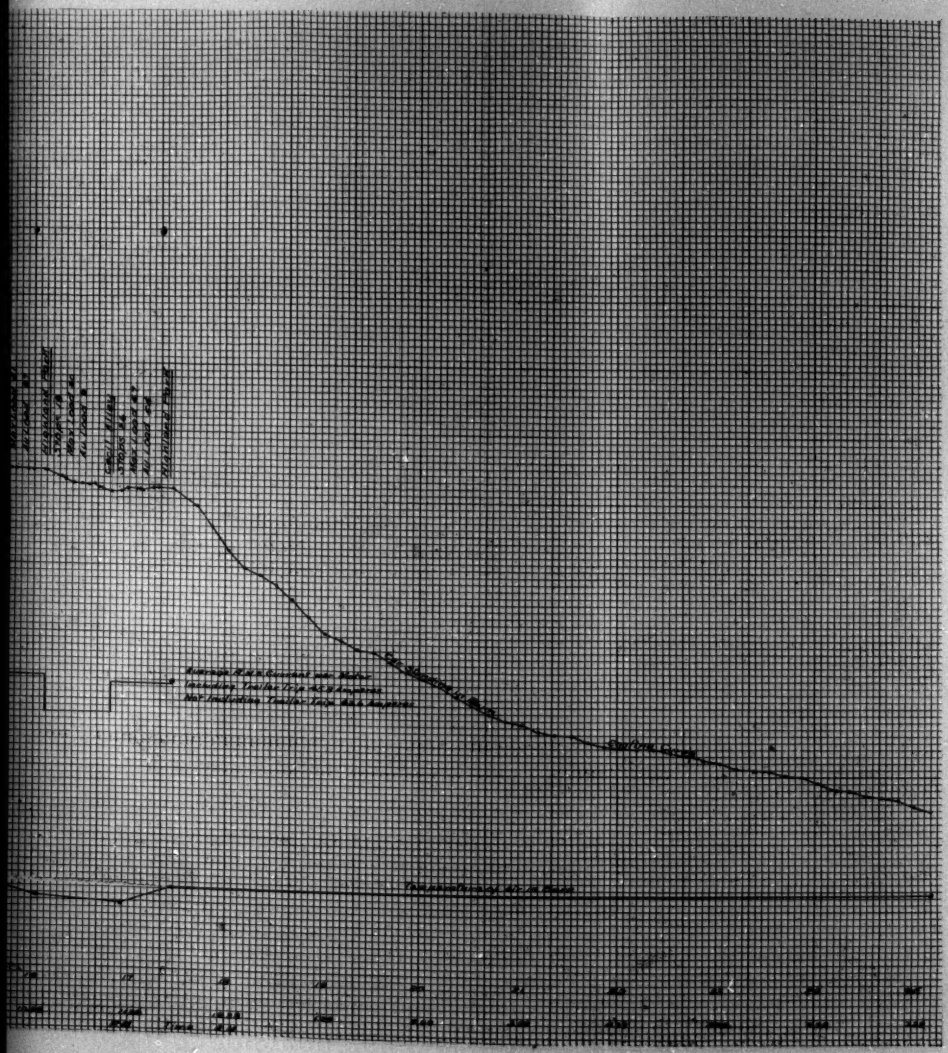


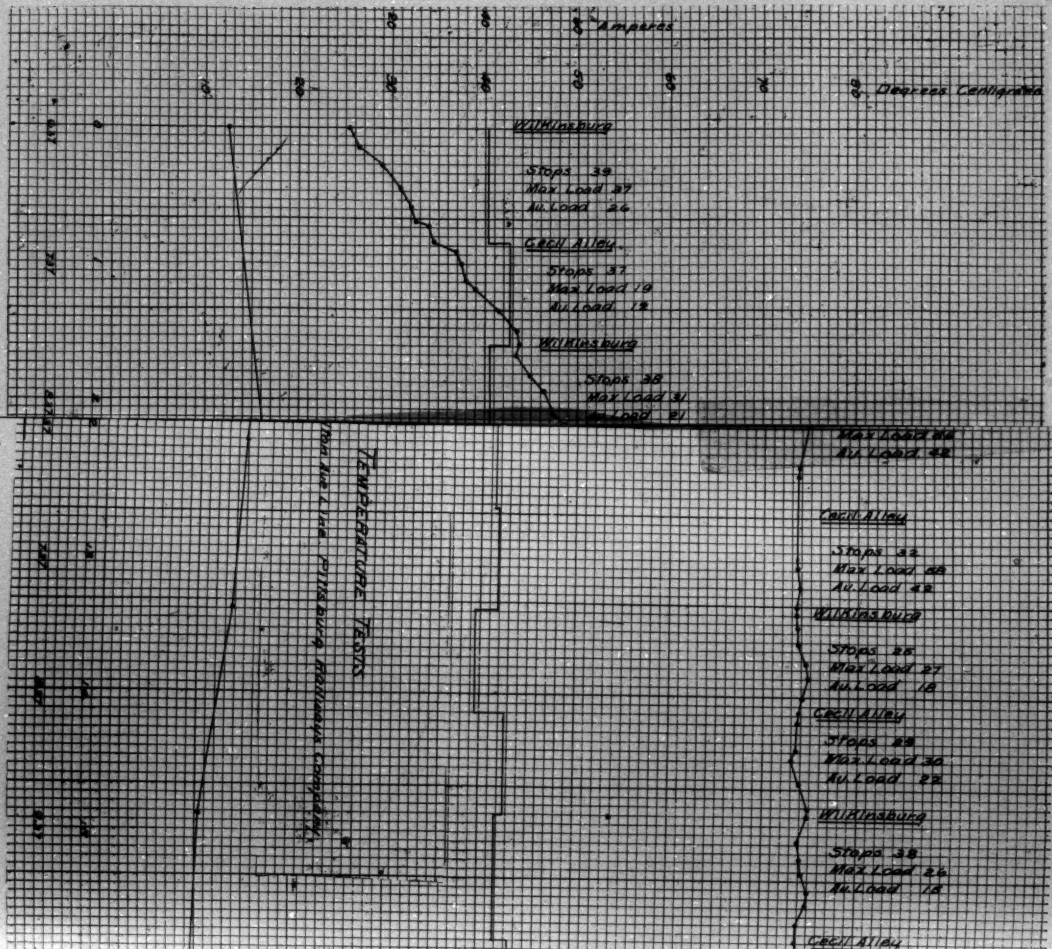
FIG. 8.—(Renshaw.)

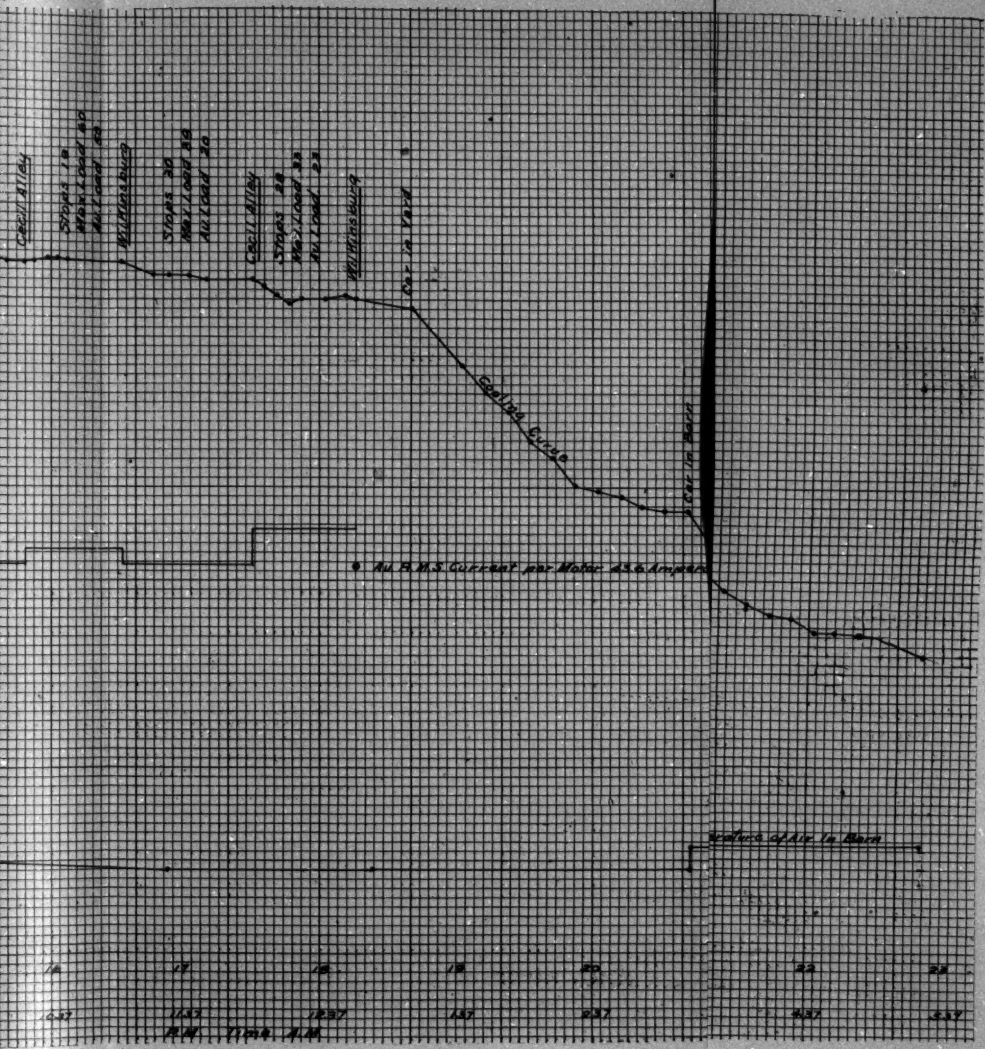


w.)

FIG. 9.—(Renshaw.)




Amperes
Degrees Centigrade
Wilkinsburg
Stops 39
Max Load 27
Av. Load 26
Cecil Alley
Stops 37
Max Load 19
Av. Load 12
Wilkinsburg
Stops 38
Max Load 31
Av. Load 21
Temperature Tests
Max Load 48
Av. Load 28
Cecil Alley
Stops 32
Max Load 28
Av. Load 18
Wilkinsburg
Stops 28
Max Load 27
Av. Load 18
Cecil Alley
Stops 28
Max Load 30
Av. Load 22
Wilkinsburg
Stops 38
Max Load 26
Av. Load 18
Cecil Alley


Ceiling Limit
Stops at 5 P.M. and Restarts at 7 A.M.
Maintained at 30 Knots
Stops at 10 P.M. and Restarts at 7 A.M.
Oscillating Speeds
Stops at 11 P.M. and Restarts at 7 A.M.
Oscillations
Run at 30 Knots
Cooling Curve
Rise in Temp.
0.11 R.M.S. Current per Meter at 5.6 Amperes
Temperature of Air in Room
18
19
20
21
22
23
6 P.M.
12 M.
6 A.M.
Time

month, vary from 39.8 amperes to 46.6 amperes. This is quite a remarkable uniformity.

It will be noted from Fig. 8 that the effect of the two rouud trips with the trailer changed the all day average root mean square current only from 43.6 to 45.8 amperes. During the trips when the trailer was hauled, however, the load was quite large and it will be seen that the difference both in the maximum and in the average temperature, caused by the addition of the trailer, was considerable. It will be evident from this that in selecting motors, or in determining the loads carried by them, any special service involving the carrying of extra loads for any length of time should be considered separately whenever the length of time has anything greater than a momentary value.

The two lines on which the tests were made, naturally divide themselves into three sections. The first of these is a loop in the down town or business portion of the city about a mile in length where the car is run very slowly and makes frequent stops. On this portion of the road there is great congestion due to the large number of cars and the movement of any given car over this portion of the route is largely a succession of jerks. The second division is from the end of this loop (High St., see Fig. 9), to Atwood St. This portion contains several long, heavy grades, the most important of which, 2½ per cent. for 3500 feet and 4 per cent. for 3000 feet, are in the same direction. Comparatively few stops are made on this section. The third portion of the road is from Atwood St. to the outer terminus of the line. On this part of each line the grades are lighter and occur alternately up and down in shorter lengths. There are also few obstructions and a high speed is made. The time required on the first two portions of the road is about the same as that required on the third portion. In order to estimate the relative severity of the service on these different sections, the root mean square current was calculated for a number of round trips over each. The average for these trips was 40.5 amperes for the first section, 41.8 amperes for the second section and 45.6 amperes for the third section. The speeds which are made on these different sections may be seen from the paragraph under that heading. These results are particularly interesting as showing, that although the average root mean square current for the trips *up* the heavy grades, was 50 amperes, the average for the *round trips* over this section was not materially different from that on the remaining sections and was even less than that on the third section, where the track is most nearly level.

Schedule Speed.

The length of the route over the Hamilton Avenue line is 8½ miles. The running time was in general about 95 minutes for the round trip, making a schedule speed of 10.7 m.p.h. On the Highland Avenue line the distance is 7⅛ miles and the running time for the round trip was 76 minutes. The schedule speed on this line was thus 11½ m.p.h. In the down-town section of the city about 14 minutes is required to traverse a loop 5500 feet in length. The schedule speed over this distance is thus approximately 4½ m.p.h. Over the second section of the road, between High St. and Atwood St., the distance is 11,000 feet and the schedule speed approximately 11 m.p.h. Over the third section, the schedule speed on the Hamilton Avenue line was 11.6 m.p.h., and on the Highland Avenue line 12.35 m.p.h.

Stops.

Figs. 7 and 8 show the number of stops for each trip during those runs. The average number of passenger stops per round trip on each of the different routes was calculated and showed a value between 4 and 5 stops per mile. It is estimated that the practical stops required at curves and crossings, in addition to the stops for passengers, would make the total number of stops about 6 per mile. The length of stops varied from zero seconds, that is, a mere slow down, up to about 15 seconds. The average duration of stop for the run shown in Fig. 7 was 4 seconds.

Passengers.

The maximum and average passenger loads for each trip of the respective all-day runs are given on Figs. 7 and 8. The net passenger load was calculated each time a passenger entered or left the car and these net loads were averaged. The average loads given in Figs. 7 and 8 were thus figured without any reference to the distance which the passengers were carried. For the run in Fig. 7 the net passenger load on each trip was plotted, with the distance as a basis, and the average loads were figured also from these curves with reference to the distance travelled as well as to the number of passengers. The results found in this way, however, differ only very slightly from those calculated on the other basis. Fig. 9 shows these passenger loads for the various up trips. The curves for the down trips are in general similar to the reversal of these curves. It will be noted that on this line most of the passengers have to be carried over a considerable portion of

the route. The car loads while passing over a very short distance, carries almost the entire load about six-tenths of the length of the route and then discharges it gradually. It will be seen from Fig. 9 that the car carried 457 people during the day on the outbound trips. The number carried on the inbound trips was 499, making a total of 956 in 18¼ hours, or 52½ per hour. The average load, as calculated from Fig. 9 and the corresponding curve for the other direction, was 24 passengers, or six-sevenths of the seating capacity of the car.

In presenting Part I. of this paper, novelty and originality is claimed only for the treatment of the ideas, not for the ideas themselves. By using as illustrations the results of actual tests rather than of calculations and by separating the matter entirely from any discussion as to how the allowable loads for motors should be determined, it has been sought to bring out the simplicity, accuracy, and general utility of this method of equating service loads. It is further desired to emphasize the fact, already pointed out, that it is the common tendency, even at the present time, to select motors which are too small and that a simple method of determining the fundamental questions—what the service loads on a railway motor are in an actual case, or what they will be in a proposed case, and whether these loads are within the capacity of a given motor or not—has a wide field of usefulness which a more elaborate method would be unable to reach.

Part II. has been included not only for the sake of the results shown, which in themselves are interesting and instructive, but also to illustrate the methods employed. Particular attention is called to the method of measuring the watts lost in the field of a motor by means of a railway type wattmeter and of deducing the value of the root mean square current from this. Under ordinary circumstances, where it was desired to use this method, the resistance of the field coils at the beginning and end of the test could be measured by means of the current and voltage drop, or in any other convenient way. The method is a simple and convenient one and used with care will give results not materially less in accuracy than measurements of power made by a similar instrument.

The writer is indebted to the Westinghouse Electric and Manufacturing Company for the various curves and results upon which the paper is based.

Discussion.

Dr. Cary T. Hutchinson:—In a paper presented to the Institute January 24, 1902, I described a method for determining the motor capacity and energy used for any schedule. Since that time I have extended the scope of this method and have made it to include the predetermination of the temperature rise of a motor when operating on any schedule, knowing the heating constants of the motor to be used.

In the first paper the datum point for these motor curves was the load determined by the "hour rating"; that is, the load the motor will carry for one hour with a temperature rise of 75°C. when tested on the stand; these limitations made the results given in the first paper seem applicable only in special cases. I have now broadened the treatment so that the datum point may be considered the input that the engineer chooses to assume for the motor when operating at full speed with resistance out; that is, the maximum power input for the run. This may be the commutation limit of the motor, or some definite proportion of it, as 75 per cent. This generalization is justified by the fact that the speed curve is very nearly a rectangular hyperbola and consequently the ordinates are in inverse proportion to the abscissae.

By reason of this independence of the shape of the speed curve of the relative point on the motor characteristic assumed for the datum, any value may be assigned to the power that a particular motor may deliver during initial acceleration; that is, any power up to the commutation limit; it may be assumed to be less than, equal to or greater than the power denoted by the hour rating, but whatever value is adopted, the motor capacity as limited by commutation is thereby fixed, since the results are expressed in terms of that input denoted by the datum point. Therefore it only remains to determine the conditions under which the motor must be used to attain the limiting temperature elevation, while at the same time not going over the limit of input determined by commutation or by the judgment of the engineer. I believe the hour rating for the input during this period is not unduly conservative; it leaves a margin for greater power on curves, grades and for emergencies.

In my first paper, I assumed that a tramway motor will, on an average, carry a heat loss of 3 per cent. of its hour load, with a temperature elevation of 75° Centigrade. This was a fair average figure and claimed to be no more. But individual motors differ materially in their heating characteristics, hence I have elaborated the method so that it may be used for motors having any $I^2 R$ loss and any core loss, and making any schedule under any initial acceleration.

I have considered the I^2R losses and core separately, and have determined for each the ratio of average loss to loss at rated load, for the several initial accelerations; having the ratio of average loss during acceleration to loss at rated load, the actual average losses for any motor are found by selecting the proper value of

the ratio and multiplying it by the loss at rated load—this being done separately for copper and core losses; the results added will give the average loss during acceleration.

The temperature elevation of the parts of a motor, as determined by tests, depends materially upon the ratio of the distribution of the total heat loss between the armature and field; hence this ratio of distribution must be determined for the several initial accelerations.

Thus I get the average loss during acceleration and its distribution; to get the average loss during the run, it is necessary to determine the ratio of time of acceleration to time of run for the various initial accelerations, and for all values of the through acceleration.

Knowing then the average loss during the run and its distribution between armature and field, the temperature elevation of the motor can be determined by comparing this average loss with the temperature rise per watt lost, as determined by tests made under service conditions giving the same ratio of distribution of losses.

The time is so short that I am able only to refer to these results here; later, I hope to present the matter in detail to the INSTITUTE.

GOLDSBOROUGH PAPER DISCUSSION.

MR H. G. STOTT:—In regard to Professor Goldsborough's paper on storage battery in sub-stations, I have been looking over the load carried by the rotaries and find that the maximum in any substation is 68 per cent. overload for a few minutes. As a rotary can safely carry over 200 per cent. load for several minutes, it is apparent that storage batteries are entirely unnecessary as far as substations are concerned. I think it would be very interesting if a test had been made; first, running for one week without the batteries; secondly, running the next week with the batteries, determining the efficiency at the power house during each period. I would like to ask Professor Goldsborough if such a test has been made. If the engine had been properly designed for the work they would certainly show better economy without the battery than with it.

PROFESSOR GOLDSBOROUGH:—We attempted to cut the storage batteries out of service in some of the substations, but found that doing so was rather disastrous to the efficient operation of the generating equipments as the main station, and the engineers in charge hardly felt like subjecting the generating equipments to the strain. There is a very important point though, in connection with all of this work, which I hoped to be able to develop in connection with the storage battery paper, to determine the efficiency of the whole system, with the best possible adjustment of the storage batteries, as compared with its efficiency without this adjustment

Although we had the data for making the necessary calculations for this comparison, we were unable to do so through lack of time.

Discussion of Goldsborough and Fansler Paper.

[Communicated after Adjournment by Mr. A. H. Armstrong.]

This admirable paper started out with a statement to the effect that it would furnish a clew to prospective purchasers whether or not the storage-battery should be used in substations and what capacity this battery should bear to the substation installation. This question has bothered a good many of us from time to time, and I was very much disappointed, on proceeding further, to find that the main question has been overlooked and the paper was devoted to a series of detailed tests which are interesting, but which do not consider the economical value of the battery in the station. If the tests had been carried out somewhat more elaborately, had included coal consumption in the generating station with and without the storage battery, had entered into the first cost of the storage battery and the rotary converter which it replaced, with the interest on the increased cost together with the cost of maintaining the battery in operation, it would have furnished some guidance for the consulting engineer in similar installations.

Many of our suburban roads are commencing to appreciate the effect which frequent stops and breakdowns have upon their patronage. Such roads are using protective devices of all kinds, installing expensive automatic switches, providing duplicate pole lines, and in every way endeavoring to ensure continuity of service. To engineers of such roads the storage battery appeals as a further protective device against breakdown. Most of the troubles in suburban roads result from defective insulators, or other shut downs to which their long distance transmission lines expose them. Some of these railway systems are tied up to transmission lines of over 100 miles in length, and although this transmission line is divided up into sections, may be duplicated, or may form part of a ring system, it is evident that there is the danger of occasional shut-down, more especially when the system is new. The office of the storage battery in the substation therefore cannot be considered alone from the economic standpoint of saving in coal, etc., but from the operative point of view as a safeguard against breakdown. A battery installed in a substation and having capacity enough to run the normal service for say three or four hours will afford an assurance of constant running possessed by no other device. Oftentimes its installation can be advocated by the conservative engineer when from the dollars and cents point of view it shows up on the wrong side of the balance sheet.

I would regard this point of view of the storage battery in the substation as the proper one, as it is very difficult to show any economy in operating expenses by the use of the storage battery unless coal is abnormally high and storage batteries abnormally cheap.

Discussion of Renshaw Paper.

[Communicated after Adjournment by Mr. A. H. Armstrong.]

Mr. Renshaw has given us the analysis of a series of service runs on railway motors which is a step in the right direction. There is too little experimental material obtained and too little regard paid to the proper selection of this type of apparatus, which has a value exceeding that of the generators and rotary converters feeding into them. As this paper was, however, presented probably for the information of consulting engineers and not designing engineers, I do not see the use of the term "square root of the mean square current per motor." While this value was very carefully and probably accurately obtained, it was put to no practical use, that is from the consulting engineer's standpoint. An engineer has to face the problem of selecting a motor to do a certain piece of work. He is the best judge of the conditions under which the motor will operate in a prospective system and needs the material at hand by means of which he can select, according to his best judgment of temperature rise and money expended, the proper equipment for the case in hand. After reading Mr. Renshaw's paper he will become imbued with the idea that the proper thing to do is to obtain the square root of the mean square current of an equipment operating over the profile of his route under service conditions. Unfortunately, however, there is no direct connection between this square root of the mean square current and the heating of the equipment to be chosen. Having obtained the square root of the mean square current, it will, it is true, furnish the basis of calcualting the copper losses of motor, provided its resistances are known. Were the motor constructed so that it would operate without a core loss, this value would be very valuable and probably give directly, with a factor, the heating of the motor for any class of work. The core loss, however, is so variable in quantity and distribution, and withal forms such a considerable part of the total motor losses that it cannot be ignored in this arbitrary manner. The fact further that the motor may be run upon the stand at the square root of the mean square current and that a voltage giving presumably the proper core loss will also fail to furnish the necessary basis for motor calculations, owing to the difference in ventilation upon the stand and upon the trucks and also due to the fact that the core loss is not distributed properly at the arbitrary stand voltage chosen. The core loss also does not correspond with the average voltage to which the motor is subjected when running, this loss on the contrary being a variable depending upon the particular motor in question and the conditions upon which it is operated in service.

It is unfortunate perhaps that there is no short method yet proposed by which a railway motor can be rated and which will express its relative capacity to do work. The only accurate method known is to follow through the various losses in the

motor for a given piece of work, determine experimentally the degrees rise per watt loss, and thus obtain the temperature rise. This method entails an enormous amount of experimenting and calculation, but the results justify the expenditure of labor and time, owing to the fact that railway motors operate at nearly double the temperature of stationary apparatus and hence any considerable inaccuracy may lead to much more serious results in the selection of this type of apparatus. A motor rising 60 or 70 degress C. above the air will reach and oftentimes pass the boiling point of water, and an error of 10 or 20 per cent, may lead to disastrous results. It is just here that the square root of the mean square current fails as a means of determining the proper size of motor for a given service. While it does serve as an indication of the motor's temperature, it is an indication only and leads to no practical results.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 30, 1903.

REVERSE CURRENT CIRCUIT BREAKERS AND THE PROTECTION OF TRANSMISSION LINES.

BY LEONARD WILSON.

Engineers who have had the experience of running faulty apparatus in parallel have long recognized the inadequacy of a system of excess current protection; but the necessity for adopting reverse current protective devices is still far from being universally recognized. The advantages of reverse current protection over excess current protection are briefly: That the former cuts out the faulty apparatus and does so at the moment when only a small current is flowing, thus causing the minimum disturbance to the system; while the latter is very liable to cut out all the healthy units instead of the one faulty one and only operates when the current is excessive. It will be seen, therefore that wherever current is being fed to a common bus bar from more than one source, reverse current circuit breakers should be installed.

The evolution of the reverse current circuit breaker has been a long process and even at the present day devices are installed which do not possess the necessary characteristics for reliable operation and consequently bring discredit on this system of protection. The following are the more important of the characteristics referred to.

(1) A reverse current equal to 25 per cent. of the normal must be sufficient to operate the breakers.

(2) The magnetic pull must continue to increase with an increase of the reverse current so that any sticking of the mechanical part will merely cause the breaker to operate at a sightly higher current, and that if the reverse current suddenly

attains a very high value the operation of the breaker will be the more certain.

(3) A failure of the potential coil from whatever cause arising, must not operate the breaker.

(4) The device must in some way continuously indicate whether it is in working order or not.

With regard to the first point, it is important that the device should not be too delicate in its action, and to obtain this, the relay is in some cases provided with a time element. This, however, does not produce very satisfactory results as it allows the current (when there is a serious fault) to rise to too high a value. The best practice seems to be to have quick-acting relays set for a moderate return current, 25 per cent, having been found a very

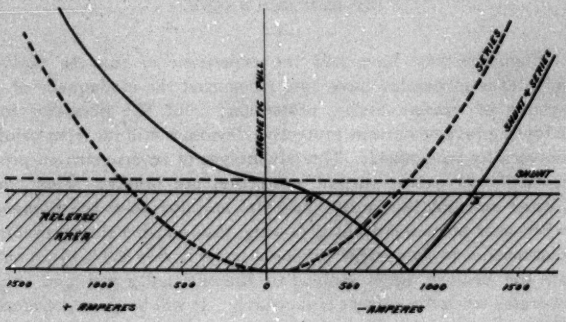


FIG-1

suitable value. If for any reason, a combined reverse and excess current breaker is required it will be found better to provide two separate tripping-coils as a combination of the two in one necessitates a certain compromise in the characteristics of the device. A convenient method of illustrating the action of devices of this kind is that of plotting characteristic curves showing the relation between the operating force and the current producing it.

The force that will just operate the device is shown by the boundary of a shaded area and the part of the curve lying outside this area indicates the range of the current at which the breaker remains closed. Fig. 1 shows the characteristic curves of a circuit-breaker which operates when the magnetic pull falls below

a fixed value, and it will be seen that in this type the curve crosses the boundary of the shaded area at two points, A and B. In consequence of this, if the reverse current suddenly attains a value higher than B, the device will fail to operate. Also it will be noted that an interruption of the shunt current will operate the breaker. Fig. 2 shows the curve of a circuit breaker which operates when the magnetic pull, due to the product of the series and shunt current, exceeds a certain value; and it will be seen that the objectionable features of No. 1 curve are absent from this.

It is unnecessary to describe in detail any particular form of reverse current circuit breaker, as such information is readily obtainable from the bulletins of manufacturing companies, but a

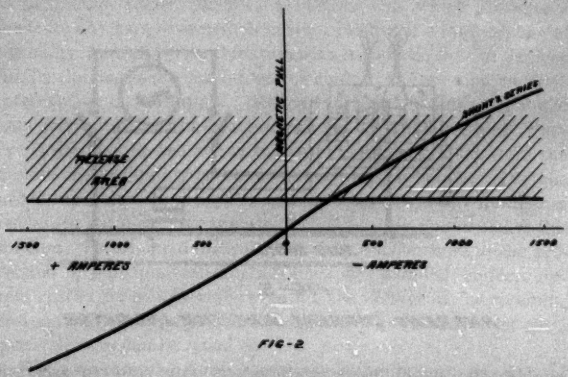


FIG-2

short description of a device, novel in this country, together with a demonstration of it in operation, may prove of interest.

Some operating engineers prefer to trust to the switchboard attendant in case of trouble rather than to install any form of automatic circuit-breaker, but in such cases it is very necessary to have some visual signal to indicate which of a number of generators is the faulty one. For this purpose, some form of wattmeter relay arranged so close a local lamp circuit may be used; but a simpler and more reliable device is the one illustrated in Fig. 3. This device, invented by Mr. L. Andrews of England, consists of a double magnetic circuit magnetized by shunt and series windings and provided with two secondary windings connected to red and green signal lamps. In the diagram, A A is the

shunt winding, connected across the station bus-bars and B is the series winding, consisting of one turn of the main cable connecting the generator to the bus-bar. With only the shunt winding excited, the secondary coils c c have each half the normal lamp voltage induced in them, and consequently both red and green lamps glow faintly. When the generator delivers current to the bus-bar, the action of the series winding is to neutralize the flux through one secondary winding and increase it through the other, thus extinguishing the red lamp and lighting up the green one; conversely, when the current reverses, the green lamp goes out and the red one lights up. This device appeals to operating engineers by its simplicity and the complete absence of moving parts. The use of two lamps (preferably each in duplicate)

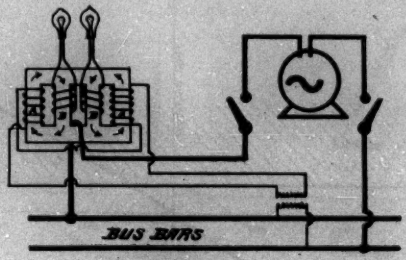


FIG-3

ANDREWS CURRENT DIRECTION INDICATOR

enables the switchboard attendant at any time to ascertain whether the devices are in working order, for whichever direction the current is flowing in and however small the current, it will produce a difference in glow, between the red and green lamps, which indicates that the device is operative.

The protection of the transmission lines presents many problems of interest. The simple case where the feeders starting from the bus-bars transmit power to separate receiving points is taken care of by excess-current circuit-breakers; but where the feeders are also connected together at the receiving end, some other system of protection is necessary. An efficient system of protection for multiple transmission lines should, while normally allowing all the lines to be in use at once, be capable of preventing any excessive rush of current in case of a fault on one of the lines

and should include devices for entirely cutting out such faulty line without serious disturbance of the rest of the system. Attempts have been made to provide such protection by the use of excess-current breakers at the generating end and reverse current breakers at the receiving end, but with very little success, the failures being due to one or both of the following defects in the system:

(1) That it does not prevent the sudden rush of current through the healthy mains to the faulty one.

(2) In the case of a low resistance fault the pressure falls so low at the receiving end that the reverse current-breakers (if they depend on the action of potential coils) fail to operate.

The system devised by Mr. L. Andrews, which is briefly referred to in another paper, includes a choking-coil which absolutely prevents any excessive rush of current in case of a fault on one of the mains, and this in combination with automatic cut-out devices fulfills the necessary conditions for complete protection without interruption of the supply. As used in England this system has only been applied to duplicate mains, and for this a single choking-coil is used connected across the two mains, with a tap from the middle of the winding going to the receiving apparatus. By the use of more chokers the system can be adapted for any number of feeders in parallel. By the use of choking-coils connected in this manner, the principal difficulties usually encountered in the protection of multiple transmission lines, are avoided; sudden current rushes are absolutely prevented, the voltage at the receiving end is maintained, and consequently the operation of the automatic devices can be relied on.

Fig. 4 represents a duplicate transmission line protected at the generator end by excess-current circuit-breakers and at the receiver end equipped with differential choke-coils. For the sake of simplicity, only one polarity of the system is shown thus equipped. When a short-circuit occurs on, say, B feeder there is a big rush of current from the generator to the fault through B and this operates the excess-current circuit-breaker at the generator end. Without the choking-coil, there would also be a rush of current to the fault via the healthy feeder and this would very probably operate the remaining circuit-breaker and interrupt the supply. The choke-coil entirely prevents this for as soon as the current flow in the two halves becomes unbalanced, an e.m.f. is induced which opposes the unbalancing, and the only current which flows to the fault through the healthy feeder is that

required to magnetize the choking-coil. While the short-circuit is maintained and before the faulty feeder is cut out, the receiver voltage will be 50 per cent. of its normal value. The switch B, being thrown, the faulty feeder is cut out, the choking-coil short-circuited and the supply is continued at normal voltage. In the apparatus exhibited, a special form of automatic device is used for operating the feeder switches and this device is illustrated diagrammatically in Fig. 5. The two small transformers are each magnetized by two windings connected across the system so that the induced flux of one of them depends on the voltage of

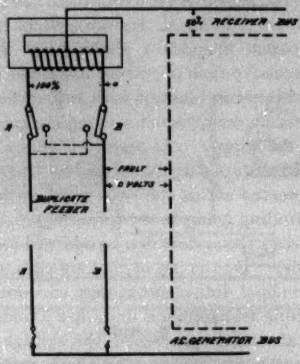


FIG-4.

DUPLICATE FEEDER PROTECTION
(CONDITION WHEN B FEEDER HAS FAILED)

the particular feeder and the other on the mean voltage of the two feeders. Referring to Fig. 5, the coils A and B are excited from the feeders A and B while coils C C are connected as shown from the common terminal of A and C to the opposite polarity of the system. Normally the two windings on each transformer magnetize in the same direction; but in case of a short-circuit on one of the feeders, while the current in C C will continue in the same direction, the current in the coil connected to the faulty feeder will reverse and the opposition, of the two windings will send a flux through the middle leg on which is wound the secondary coil connected to the release-coil of the feeder switch.

As the essential feature of the Andrews system is the use of the special choke-coils, a few words on the design of these coils is necessary. Under normal conditions there is no flux in the iron core and the only losses are those due to the ohmic resistance of the coils. When a fault occurs the ampere-turns of the two coils will be unbalanced and the resultant of the two will produce a magnetic flux which reacting on the windings will tend to prevent the unbalancing of the currents. For complete protection, it will be seen that this flux must be sufficient to induce the full

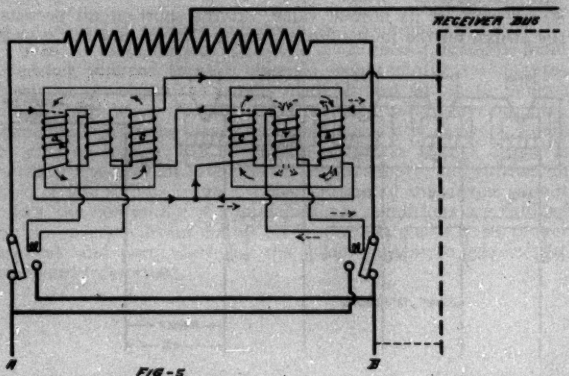


FIG-5

(BROKEN-LINE ARROWS SHOW CONDITION WHEN B FEEDER HAS FAILED.)

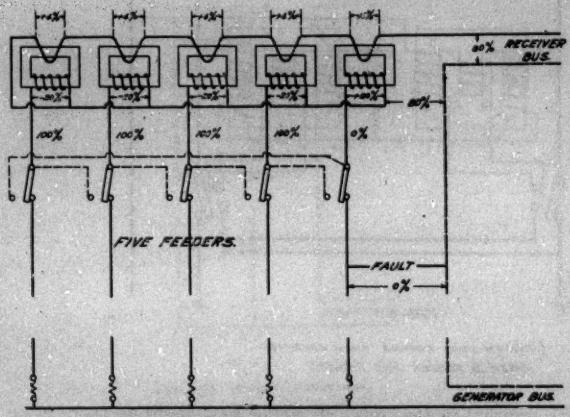
line pressure in the coils, but under this condition there is no objection, to the iron being highly saturated; and consequently by careful attention to the design, a very compact choke-coil can be produced.

To sum up, the use of choke-coils in this manner will introduce a small extra copper loss into the system, in return for which it will confer complete freedom from trouble due to short-circuits on the line by its direct action of choking back the short-circuit current.

Discussion of Wilson Paper.

Mr. H G. Stott:—I would like to inquire how that device can be applied to more than two lines.

Mr. Wilson:—The accompanying diagram shows the method of protecting five parallel feeders. For simplicity only one side of the system is shown protected, but if necessary the other side can be similarly protected, in which case the size of each choking coil will be one-half. In the case of a dead short-circuit occurring on one of the five feeders, the rush of current from the four healthy ones will be prevented by the choke-coils and without operating any switches at all the system will continue to operate with the receiver voltage reduced by one-fifth, *i.e.*, reduced to 80 per cent. of its normal value. If the short-circuit persists, the switch on the faulty feeder can be thrown and the system



AUTOMATIC PROTECTION OF FIVE PARALLEL FEEDERS.
(CONDITION OF ONE FEEDER DEAD SHORT CIRCUITED.
FIGURES REFER TO PERCENTAGE OF NORMAL VOLTAGE)

will operate at normal voltage with one feeder taking up double the load of each of the others. The extra drop in this feeder will be automatically compensated for by the choke-coils, so that there will be no appreciable change in the regulation of the system, due to the cutting out of the faulty feeder. If the fault is a high resistance one, the effect on the receiver voltage will be very small. With such a system perfect protection is obtained without operating any switches at the receiver end, and signal-lamps connected across the choke-coils afford the necessary indication for localizing the fault.

President Scott:—The point Mr. Stott has in mind is, if he has a 3-phase circuit with 10 or 20 feeders, sufficient devices of this kind might fill up his station.

MR. WILSON:—That is quite so, for a large number of feeders.

[COMMUNICATED AFTER ADJOURNMENT BY MR. LEONARD WILSON]

In discussing the adoption of automatic protective devices, it must be remembered that the true function of such devices is to assist in maintaining continuity of supply, and from this standpoint they readily divide themselves into three classes:

(1) Devices which by prompt action prevent a faulty part of the system from interrupting the supply, but cannot under any circumstances themselves interrupt the continuity of supply.

(2) Devices which while protecting the rest of the system from being interrupted by a local fault, in so doing themselves interrupt the continuity of supply at that point.

(3) Devices for the protection of apparatus but not directly instrumental in maintaining continuity of supply.

In many cases, devices of the two latter classes should be hand operated, whereas, those of class (1) should in all cases be automatic, as the objections usually made against automatic devices do not hold when the conditions are such as are here implied. The ideal condition, therefore, for an automatic device is where in case of trouble the immediate operation of the device is necessary to prevent interruption of the supply, and further, in case of less serious trouble, the operation of the device cannot affect the continuity of supply. These conditions are fulfilled by the reverse-current circuit-breaker (when placed in its proper sphere), and particularly by the feeder protective system previously described.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

METHODS OF BRINGING HIGH TENSION CONDUCTORS INTO BUILDINGS.

BY C. E. SKINNER.

One of the points in the design of high-tension transmission lines which seems not to have received general attention is the method of supporting and insulating the conductors which connect the transmission circuit with the apparatus in the generating stations and substations. Each engineer follows the plan which seems to him best for his particular set of conditions. In some cases the line is brought through a hole in the wall; in others, through an elaborate system of tubes placed in the wall; in others, through a piece of insulating material of some kind set in the wall; in others, the line is entered through an elaborate tower built for the purpose on the top of the building; in still others, it is taken directly through the roof of the building.

It is manifestly impossible to prescribe any fixed method for all voltages and all locations, as the requirements of each plant are varied by the local conditions, but much would be gained if the general requirements were outlined in such a way that designers of buildings and designers of plants could follow some general and accepted scheme which is known to be satisfactory for any given set of conditions. It is the purpose of this paper to discuss the general requirements rather than to give specific designs, although specific methods must necessarily be referred to in this discussion.

The method to be followed will depend on the following conditions:

(1) The voltage of the transmission circuit.
(2) The climate in which the plant is operated.
(3) The size of the high-tension conductor.

(4) The kind and height of building used.

(5) The conditions of approach to the building and the location of the apparatus in the building to which the high tension line is connected.

The requirements which must be met are:

(*a*) *The Maintenance of Proper Insulation of the Circuit.* To maintain proper insulation, it is necessary either to allow sufficient open space about the wire to prevent any possibility of the current striking across to the walls or surrounding material; or some insulating medium, such as a tube, must be applied to the wire to give the proper insulation.

(*b*) *The Prevention of the Entrance of Rain, Snow, Cold Air and Dust.*—The entrance of moisture, snow, and dust, should be prevented both on account of damage to the contents of the building, and on account of the weakening of the insulation at the point of entrance. In most climates it is necessary that all openings be closed for at least a portion of the year.

(*c*) *The Proper Mechanical Fastening of the Line Wire.*—The end-strain of the line must be taken up, and it is often convenient to combine the plans for taking up this strain with those for entering the building. This is particularly true where the transmission conductors are very large. It is also necessary to hold the wire in a fixed position where it passes through the opening into the building. This requires a more rigid line construction than is necessary away from the building.

(*d*) *Reliability and Simplicity of Construction.*—It is self-evident that the construction must be such that it will be reliable under all circumstances. There are usually a sufficient number of troubles on high-tension transmission lines due to circumstances beyond the control of the engineer, without introducing any extra risk at the point where the wire enters the building. Usually, as in most other work, the simplest form of construction will be found the most reliable.

In general, wires are best brought through the walls of the building. The simplest form of construction consists merely of an opening in the wall sufficiently large to allow the proper air insulation between the wire and the wall, this opening being suitably protected from rain either by means of a large pipe set in the wall, sloping outward, or by a sufficient extension of the roof above, or both. The requirem nts of this form of construction are that the wire be a sufficient distance from the pipe, so that there will be no possibility of striking across under

any conditions. The pipe should always be considered as "ground," regardless of the construction of the building. The cross-arms holding the wire inside and outside of the building should be sufficeintly near and so braced that the wire will remain central in the pipe. This construction can be used to advantage only in dry, warm climates.

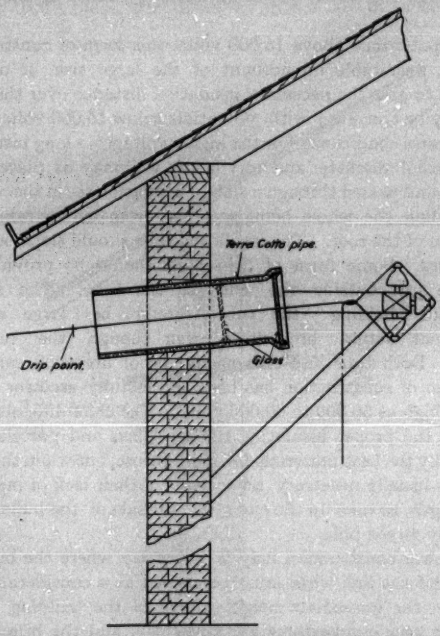


FIG. 1.

In most climates provision must be made for keeping out rain, snow, etc. With potentials of 15,000 volts or lower a disc of glass or other fireproof insulating material placed over the wire at the inner end of the pipe will usually accomplish this purpose. In this case the tube must be sufficiently large so that the surface insulation over the insulating disc used will be ample to prevent trouble under the worst conditions which may occur. When there is any danger of condensation of moisture due to differences of

temperature inside and outside of the building, two discs a little distance apart should be used. These discs may be cut so as to be placed in the pipe itself, or they may be cushioned and simply swung on the wire, lying against the ends of the pipe. The surface insulation of the discs used should never be less than that of the line insulators, and as they will usually be less advantageously placed than the insulators, extra distance should be allowed, if possible.

With potentials above 15,000 volts, this form of construction becomes unsuitable on account of the large size of opening required to give the necessary insulation distance over the discs. This may be true even with potentials below 15,000 volts under very adverse conditions. For the higher voltages, a long insulating tube of small diameter and very heavy wall may be placed over the wire and passed through a slab of insulation set in the wall of the building, the whole being protected from driving rain by an extension of the roof. The insulating tube should slope outward in all cases. Some form of drip point should be provided on the wire just outside the end of the tube. The insulation slab holding the tube should be large enough to prevent actual breakdown even though the tube is broken. Both tube and slab should be of fireproof material. This form of construction has been successfully used for potentials as high as 50,000 to 60,000 volts. The chief difficulty is in securing the proper insulating tubes. Glass and porcelain are electrically the best materials for the purpose, but when these are used it is usually necessary, on account of their lack of mechanical strength, to take up the end strain outside of the building by a suitably guyed pole.

The tower-construction may be necessary where the building is low, and the line wires must be carried at a considerable elevation in the immediate neighborhood of the building. It is generally very cumbersome and unsightly, and the bringing of the wires through the side of the tower presents the same problem as bringing them through the side of the building.

The bringing of the wires directly through the roof of the building, while possible, requires that extra precautions be taken to secure sufficient insulation and to keep out all moisture. This method, however well carried out, will probably constitute a danger point in the system.

In general, no combustible material should be used near the line wire, even when separated from it by insulating material

sufficient to withstand the strain. Leakage or brush discharge is liable to cause burning sooner or later, and such burning is more serious at the building than the burning of a pin or cross-arm on the line.

The accompanying illustrations, Figs. 1 and 2, are intended to show diagrammatically the two general plans recommended in this paper. Both plans, practically as shown, are in successful use

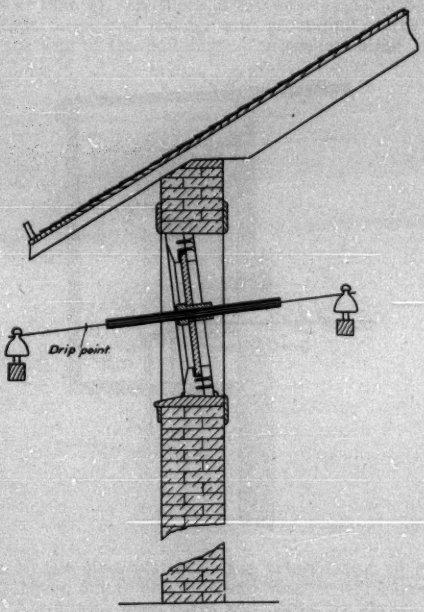


FIG. 2.

by important transmission plants. It is expected that each engineer will find it necessary to make changes in details to suit his particular case, but it is believed that the plans proposed may be made effective for any transmission circuit.

The method of bringing high-tension wires into buildings should be carefully considered at the time the building is designed and proper provision made. It often happens that this point

is given no consideration whatever, and the result is an unsightly and unsuitable arrangement made after the completion of the building and at an increased expense.

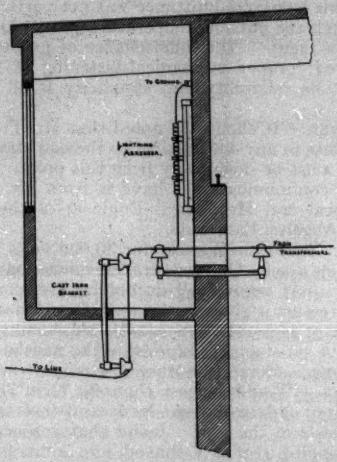
It is hoped that those having practical experience with the design and construction of this particular feature of the transmission line will take an active part in the discussion of this paper, and that by this means the INSTITUTE may be able to furnish general recommendations covering this subject.

Discussion of Skinner Paper.

Mr. Skinner:—I have here several communications which I will read.

Mr. Henry Floy:—Because of its simplicity and reliability, the writer believes there is nothing quite equal to a plain but generous hole in the wall through which the wire rigidly supported, may pass. This form of construction modified as hereafter shown, is applicable to any voltage, and almost any climate.

I consider that the use of glass plates, as suggested by Mr. Skinner in Fig. I., or conductors insulated for a portion of their length as in Plan II., are more or less objectionable because of the constant menace of leakage and grounding of the system, through the wall of the building. The accumulation of dust or



moisture on the glass plates, or the deterioration of rubber or paper insulation due to exposure and weather will sooner or later end in a shut-down; glass tubes and plates are always breaking and never make a really good mechanical job.

If the station is provided with an overhead traveling crane, it will usually be found more convenient to bring the wires into the building through one of the walls rather than into a tower.

Having tried several different methods, none of which were wholly satisfactory, the writer devised the scheme shown in the accompanying sketch, which explains itself. This form of construction has been successfully used in a concrete-steel building, where the roof beams of concrete were carried beyond the walls

of the building and made to support a gallery, which serves as a lightning-arrester house; thus, the satisfactory introduction of the wires into the building and a proper fireproof room entirely separated from the station for the location of the lightning arresters, is provided. The iron brackets on which the wires are first supported, may be set either in the floor of the gallery or in the wall of the station. In either case all water drips from the wires before the latter turn vertically to pass through the floor of the gallery. At the same time any small amount of rain, snow or dust which may blow up into the gallery will not continue on through the second hole into the station. Moreover, the two apertures, one leading into the gallery and the other from there into the station, being at right angles to each other, prevent any large amount of cold air entering the station. One building provided with this form of admittance was not particularly uncomfortable though the outside temperature was as low as 27° Fahrenheit below zero. The maintenance of proper insulation is always insured; proper mechanical fastening of the line wires secured, and the reliability and simplicity is all that could be desired.

MR. SKINNER:—It should be noted that Mr. Floy's plan does not contemplate in any way taking up the end strains of the line wires. This must be done away from this point.

The other communication I have is from Mr. O. H. Ensign, Chief Electrical and Mechanical Engineer of the Edison Company of Los Angeles, California.

MR. O. H. ENSIGN:—We use, for 30,000 volts, plain 12-inch sewer-pipe wide open. Our temperature never goes to zero. It is cold only for short periods. I do not believe that unless considerable protection is given in the way of extension of the building, any sort of glass plate or marble supporting special insulators would be satisfactory, exposed to the weather.

MR. SKINNER:—Here is another discussion by A. L. Mudge.

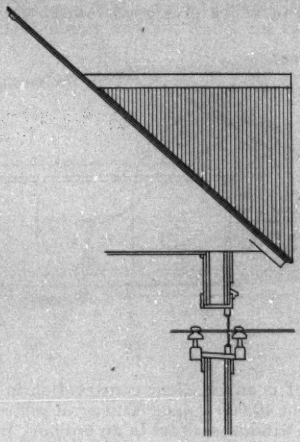
MR. MUDGE:—Would suggest that the terra cotta should be closed at outer end to prevent birds and insects getting into or building nests in the pipe. I find that a good ice and snow break on a sloping roof is V-shaped, and is much stronger than a single horizontal strip and also tends to let the roof free itself of snow. These strips can either be made of wood or of two lengths of angle iron bolted to the roof.

PRESIDENT SCOTT:—Another from Mr. F. C. Pierce.

MR. PIERCE:—Referring to the article: Page 1172, Art. (5), (C), I do not believe in allowing the wall of the building to take the strain of the line, the last poles of the line should be braced or guyed; the number of poles guyed being determined by the number and weight of the line wires. In all cases I have seen, the wall, even if very heavy, will eventually come loose or bulge.

Where the strain is taken on the line; a X-arm just outside and one just inside the wall, fastened rigidly to the wall, will hold the wires in the centre of the slab of insulating material and exert no strain thereon.

I enclose rough sketch of our method of entering wires in the power house.



We found it necessary in cases where we enter under the eaves as in the sketch on p. 1175, Fig. 2, to put a false dormer above the entrance, as otherwise the ice and snow slides down, catches on the wires and accumulates between the wires and eaves until the wires are either broken or pulled out of place.

The substation wires enter the gable ends. The slab of insulating material is 12″ x 12″ plate glass with 2″ hole through center. Since putting the dormer on power house we have had no trouble whatever from our entrance wires.

[DISCUSSION CONTRIBUTED BY J. HARISBERGER.]

My experience has been with the construction as shown in sketches 1 and 2, pages 1173 and 1175. The Snoqualmie Power Company adopted at the very beginning the arrangement shown in Fig. 2, and with all of its high-tension troubles, it has yet to experience its first trouble with this style of construction for entering buildings. In some of the buildings the wires enter with the construction shown in Fig. 1 and in every instance when the high-tension lines became grounded for one reason or another, there was a discharge across the glass plate to the terra cotta pipe and which is evidence, in my opinion, that with a voltage as high as 30,000 it is not the best, unless a terra cotta pipe of an unpractical diameter is used.

[COMMUNICATED BY M. H. GERRY, JR.]

Mr. Skinner has stated the essential requirements for entering high-tension wires. There are a number of excellent methods in common use, all of which give good results when properly ap-

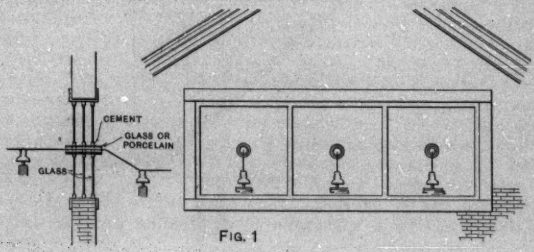


FIG. 1

plied. Fig. No. 1 is an excellent construction in use in several plants operating at 40,000 volts. This arrangement consists of a double, or triple, window sash set in an ordinary frame, the glass having openings in the center in which are placed insulating bushings, or tubes. A water shed to keep the rain from the glass is sometimes added.

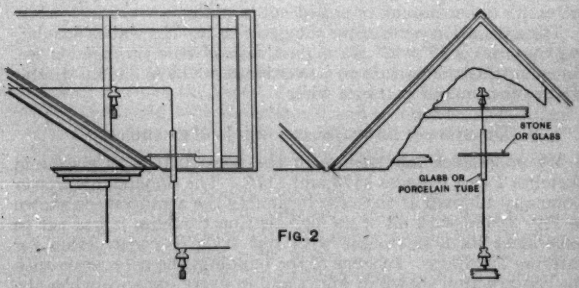


FIG. 2

Fig. No. 2 is a method frequently advocated, and in use for moderate pressures to a certain extent. It can be made to give good results, but involves special building construction.

Fig. No. 3 is a common method of entering high-tension wires through tile pipes. This method is an excellent one, and will give good results even up to pressures of 30,000 volts. Entrances of this design should always be made, if possible, through gable end of the building and not under the eaves, as shown by

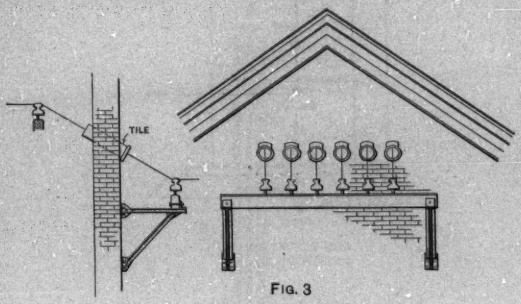


FIG. 3

Mr. Skinner. If impossible to enter at the end of the building, then a rain-shed should be provided over the wires, this being especially essential in cold climates, where ice forms readily.

Fig. No. 4 is a simple method of entering high-tension wires as applied to an iron building. The glass tubes shown are four feet in length, two inches in diameter, and from five-eighths to three-fourths of an inch in thickness. This method is now in regular use at 50,000 volts.

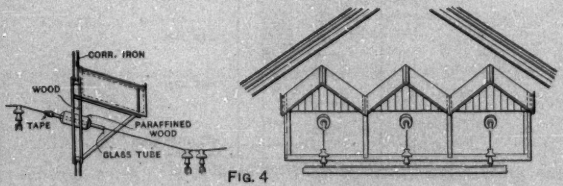
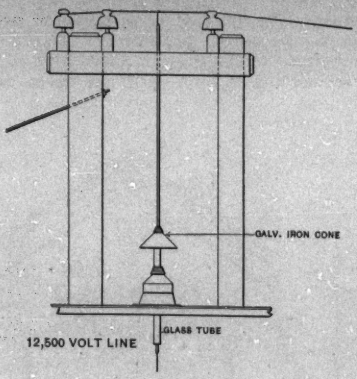


FIG. 4

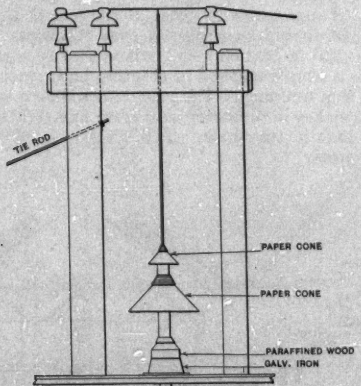
Figs. No. 5 and No. 6 are methods of entering wires vertically through the roof. Fig. 7 is a detail of the roof insulator, used in connection with the arrangement as shown in Fig. No. 6. The drawings show the construction clearly and require no explana-

FIG. 5



END ELEVATION

FIG. 6



END ELEVATION

tion. These vertical entrances are in use at the Canyon Ferry Plant of the Missouri River Power Company, and give good satisfaction. The above methods are selected as representing current practices. There can be no one method of entering high-

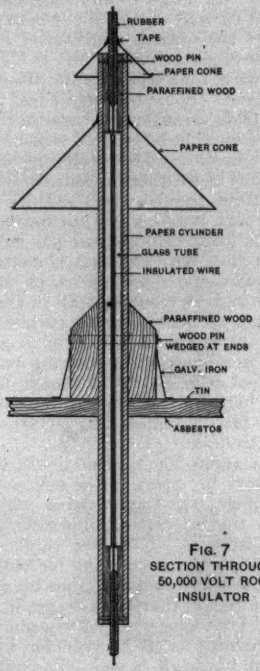


FIG. 7
SECTION THROUGH 50,000 VOLT ROOF INSULATOR

tension wires. It is always a question of engineering detail, which should receive special treatment in each particular case.

PRESIDENT SCOTT:—Mr. Skinner's paper, on the "Methods of Bringing High-Tension Conductors into Buildings" is open for discussion.

MR. MERSHON:—I have used a number of different methods of bringing wires into buildings, some of which have already

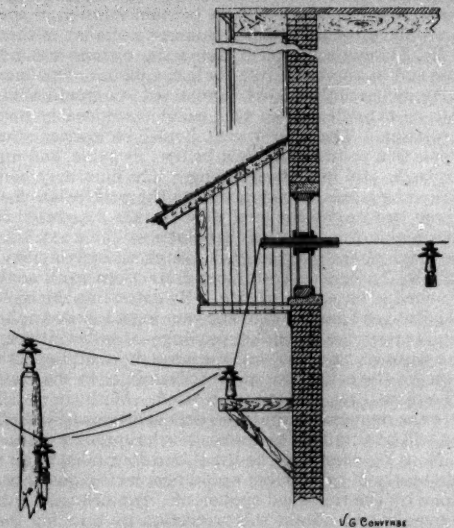
been described. The method of a tile and a flat glass plate, has been used, I think, quite a long while; also that of a glass tube in a wooden bushing going through the wall, for voltages of 25,000 or 30,000. The latter is a good method of bringing wires into buildings except for the difficulty of getting glass tubes. Some times I have had no difficulty in getting satisfactory glass tubes; at other times tubes obtained from the same manufacturer will all go to pieces if, being warm, they are subjected to a blast or draft of cold air, such as would result from opening the door of the station. So I have come to feel a little bit afraid of the use of glass tubes.

Now, as to the size of the glass plate and the distance which the voltage will go over it. Some time ago I had occasion to install a tile and a glass plate arrangement because there was not time to get anything else, and the largest tile obtainable was 24 inches. That size was put in on a 50,000 volt line which has been in operation in all kinds of weather for four or five months without any trouble. At times the frost gets so thick on the glass that you cannot see through it and, if the line has been shut down for a little while and a great deal of frost has collected, there is a discharge over the glass until the frost is melted; but after it is melted near the wire the discharge stops almost altogether. Although we have had no trouble at all in this case, I think a greater distance than 12 inches over the surface of the glass plate from the wire to the tile in a brick wall is advisable for this voltage. I think this question of entering buildings is a good deal like the question of insulators, in that it depends somewhat on the climate. There are places where the climate is such that the method I have just described for a 50,000 volt circuit would undoubtedly give trouble.

MR. R. F. HAYWARD:—There is no doubt that the question of climate cuts a very big figure in the selection of the methods for entering buildings with high-tension wires. I think this method of using a tile is open to objection, and a good deal of trouble comes from it. I do not think that any outlet which has for its protection a covering for building outside the power house where the wire comes in, then up and then through, is very nice, for the reason that birds do get in. The most successful outlet that I know of is one that was put in at the Murphy mill and has been running on 40,000 volts for, I think, four years. There is a brick wall in the gable end. The outlets are, I think, four feet apart. The holes in the brick are, I think, 18 inches. They may not be more than 14 inches. In those are set two plates of glass, each plate of glass flush with the outside, then another flush with the inside, of the brick: a hole about 2½ inches in diameter drilled through this and another glass tube placed in it. There was great difficulty, as Mr. Mershon has mentioned, in getting good glass, but they have got it, and that glass has never broken. There has never been a short-circuit or a breakdown, and that gable end faces the southwest storms, where all the

sleet and rain comes from. We are using that kind of outlet for all our work in Utah, only instead of using the glass tube we are going to use porcelain tubes, because I think we can get them stronger, and we shall simply increase the size of the plate glass to about two and even three feet square. I think that people do not appreciate how effective in practice a simple piece of plate glass is. On 16,000 volts I have a piece of 12-inch plate glass with a $\frac{3}{4}$ hole drilled in it and wires passing right through, and have never had the slightest trouble, although we frequently have severe storms in winter. I think that the most important thing in outlets is lots of space and not cumbering the outside of your building with any extra structure. Leave it clear, so that nothing can get up against it, and where everybody can see it.

MR. V. G. CONVERSE:—I am hardly prepared for an impromptu discussion, but I have a few ideas on this subject, one of which I think is of the utmost importance with very high voltages. It is that the insulation into a building should of itself be protected. It should be protected so that anything coming in a



horizontal line, such as rain, snow or dirt that is blown will not decrease the resistance of the insulation. Two figures show the extension of the roof brought down to such a point that to my mind it leaves off just where it begins to be of value.

The tile shown in Fig. 1, seems to me to possess a very bad feature in being left open on the exposed side. This construction may suffice, and I know of several cases where it is in use, but it certainly is open to the objection of being free to receive anything that may lodge in it. I think that Fig. 2 is a much better construction, but it could be improved upon by using several tubes, rested one within the other. Mr. Mershon has stated the objection to glass tubes, and I would recommend the substitution of porcelain. I do not think that porcelain is always a good article to use, but it is in this case. Suitable glass tubes are not made in this country and are very difficult to get anywhere, while porcelain tubes are a standard article of manufacture and they can be gotten in lengths up to three feet, I believe, and in a variety of diameters, which will nest very satisfactorily. I would make the further suggestion with reference to Fig. 2, that instead of one glass plate, there be two glass plates, spaced some five or six inches apart. This will give additional support, and afford an inside space which should tend to prevent the accumulation of frost. As to the point of the extension of the gable, as first mentioned, I think that there is the insulation of the whole structure. To my mind, the most uncertain point of the insulation in Mr. Skinner's second figure is the surface distance from the outer end of the tube over the glass plate. This cannot be very many inches and should be protected. I would advise that the gable be extended down to a point considerably below the wall insulation. The line wires should be carried from the anchor pole to a point several feet below this gable, and up to the tube insulators and into the building. The lines may be held in this position by a bracket supported on the wall, below the gable. If the lines are heavy they may be further supported by line insulators within the gable, so that there will be no strain on the tubes or glass plates. I furnish a sketch embodying my ideas.

MR. P. H. THOMAS:—To my mind Mr. Converse's suggestion of a rain-shed is an excellent one. By extending the roof a considerable distance from the wall and running it low down, building a baffle-plate from the ground up, leaving just sufficient opening to carry the wires in, and carrying the wires down and up as he suggests, you get the conditions of an indoor inlet at the main wall, where the plate glass and tubes are used. With the possible exception of the temperature outside, the conditions on interior construction will be admitted to be very much superior to those out of doors. Now, by changing the usual out-door inlet to an indoor inlet nine-tenths of the trouble would be avoided, and this can be easily done by the rain-shed spoken of. Sometimes it might be more convenient to obtain the protection by bringing the rain-shed inside the building; that is, have a large opening in the wall and building a small room or large box up near the top, for bringing in the wires and then putting the true inlet on the farther wall, where it would be thoroughly protected from the weather.

There is one other point; ordinarily, I think a great deal will be gained in the long run by mounting the true high insulating inlet in an insulating panel, made as nearly fireproof as possible—something of the nature of marble would of course be the best—but with a large number of substations this would be too expensive. For a great many climates, it would be wise to use a wooden panel in which to mount the glass or porcelain inlet. This panel in such a case should if possible be made of a number of different pieces of wood with the grain running in different directions, and should of course be as well treated and prepared as possible. There is a certain danger of fire, but this is a minimum, I think, with good construction, and with the rain-shed of which we have spoken.

MR. P. M. LINCOLN:—there is just one point in the scheme mentioned by Mr. Converse that I would like to bring up, and that is the matter of taking up end strain. If you adopt that scheme, you have got to take up your end strain on the line outside of the building. That means taking it up on the standard insulators with the usual pins. Unless there is a special construction it is difficult to take up the strain on a heavy line in that manner. The end strain should be taken up by a strain insulator inside, as represented in Mr. Skinner's sketch No. 1. The great advantage of that to my mind is that the end strain of the line is taken by the insulators mounted inside the building, and you can put your insulator in any position, without having petticoats in such a position as to fill up with water and become useless.

[COMMUNICATED AFTER ADJOURNMENT BY DR. LOUIS BELL.]

For all high voltages, I prefer the arrangement shown in Fig. 2 in Mr. Skinner's paper. It is thoroughly effective and has the great merit of demanding ample space between wires. A mania for compactness has been responsible for more trouble in high voltage systems than any other one cause with which I am acquainted.

Wire towers for high potential lines should be avoided, first, last and always, together with tunnels, conduits and every other device for getting high-tension wires compactly stowed away out of sight. My own personal rule is to use wide spacing and to carry all wires in obtrusively plain sight until they get out of the building and go upon the line proper.

The high voltage wires themselves and all their connections should be so placed that their whole arrangement is evident from a cursory glance, and the higher the voltage the more need for caution in this respcet.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers Niagara Falls, N. Y., July 1, 1903.

THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING.

BY RALPH D. MERSHON.

Some of the transmission lines of this country have installed upon them as a protection against lightning one or more wires strung parallel to the power wires and grounded at intervals. There is a difference of opinion amongst those operating such lines in different parts of the country as to the efficacy of this device. The importance of the subject makes it desirable to have an expression of opinion upon it from those members of the INSTITUTE who have had experience in operating such lines or who have given the matter close consideration. This can perhaps be best arrived at by a discussion on the subject.

THEORY.

There are three ways in which lightning can affect a transmission line: by a direct stroke, by electromagnetic induction and by electrostatic induction. Protection against the first of these would be almost impossible, certainly impracticable. Fortunately, lines are not often struck by lightning. The second, electromagnetic induction, is, in the opinion of the writer, a theoretical possibility—nothing more. It is against the effects of the third, electrostatic induction, that lines are to be protected, whether by lightning arresters or by grounded wires.

The theory of the electrostatic induction action may be explained with practical accuracy as follows: The whole transmission system, line, transformers, etc., may be regarded as an electrostatic conductor, insulated from the earth. Suppose a

cloud heavily charged with, say, a positive charge, to move up to the region over the transmission line. There will be a positive charge "set free" on the transmission system and it will have a tendency to pass to earth. It will pass to earth by gradual leakage over and through the insulation of the system if the approach of the cloud is slow enough to give time for such leakage; if not it may puncture the insulation and thus pass to earth. The intensity of the charge will depend upon the potential at the line wires due to the charge of the cloud. Suppose there be near the transmission wires other wires parallel to them and grounded at frequent intervals. They will also be subject to the inductive action and the charge set free upon them will pass to earth as fast as liberated, the "bound" charge of the opposite sign of that of the cloud remaining and depending for its magnitude on the potential due to the cloud and the electrostatic capacity of the grounded wires. Under these conditions the intensity of the charge on the transmission wires will no longer depend only upon the potential at them due to the cloud, but upon the combined action of the charge of the cloud and the bound charge of the grounded wires. In other words, the potential of the line wires will be equal to the difference of the potentials due respectively to the cloud and the grounded wires and will in general be less than that due to the cloud. This action constitutes what may be designated as the "shielding action" of the grounded wires.

Return now to the condition where with no grounded wires the system has been gradually charged and the charge has gradually leaked away, leaving a bound charge of negative sign on the system. Suppose now the cloud be discharged by a lightning flash to earth. The potential due to it at the transmission wires is now zero and there is consequently left upon the transmission system the negative charge which was previously "bound" but is now "free" and which has a tendency to pass to earth and will probably do so suddenly, since the charge has been rendered free suddenly. Its passage to the earth may mean a puncture of the insulation of the system. If, however, we assume that the grounded wires are again present and the charge bound on them by the cloud and set free upon them by the lightning flash can readily pass to earth, there will be less tendency towards the puncture of the insulation of the system because of the fact that, as previously explained, the impressed potential of the line wires before the flash is less with the grounded

wires than without them. If the charge on the grounded wires cannot pass readily to earth the charge on them will tend to set free a negative charge on the line wires, which will be added to that set free on the line wires by the lightning flash. The worst condition would be that under which the charge on the grounded wires could not pass to the ground at all, in which case the sum of the two charges on the line wires will be just equal to that which would have existed if there were no ground wires. The passage of the charge from the grounded wire to ground will always be more or less obstructed by the inductance of the discharge path, the effectiveness of this inductive obstruction depending upon the suddenness with which the cloud discharges. This inductive action of the ground wires due to the charge left upon them we will designate as the " direct action " of the wires.

The " shielding action " of the ground wires may be calculated by making assumptions which will approximate to a degree those which obtain in practice, but the calculation of the " direct action " is less satisfactory since it involves a number of assumptions, all more or less speculative in their nature. This is due amongst other things to the fact that we cannot know how long the lightning flash will last or whether it will be oscillatory or not. Furthermore, we do not know what the dielectric strength of the insulation of the system will be for periods of time so short as those involved under the conditions mentioned. We do know, however, that under the worst conditions that can obtain the insulation stress due to the " direct action " of the grounded wires can be no greater than though they were not present and will in general be less. We also know that whatever be the maximum value of this insulation stress it will diminish rapidly either in an oscillatory or non-oscillatory manner, the rapidity of the diminution depending upon the freedom of the discharge path from obstruction. It is to be noted that the time-element of dielectric strength is not involved in the calculation of the " shielding action " to the degree that it is in the " direct action"; since in the former case the charge comes on to the system more or less gradually and we may assume without great error that ordinary values of dielectric strength hold.

In order to get an idea as to the magnitude of the " shielding action " let us calculate its effect under the most simple conditions. Suppose we have two No. 00 wires stretched side by side on a pole line 20,000 feet in length, the wires being one foot

apart. Call these wires A and B. Suppose first that both wires are insulated from ground and that the space occupied by them is raised by the inductive action of a cloud to a potential V above the earth. The expression for the potential of a long cylinder or wire of length l and diameter d, having upon it a charge whose density is δ is

$$v_1 = 2\pi d\,\delta \log_e \frac{2l}{d}$$

The potential outside such a wire at a distance s from its axis is

$$v_2 = 2\pi d\,\delta \log_e \frac{l}{s}$$

Each of the wires A and B has upon it, therefore, a free charge of such a density that

$$V = 2\pi d\,\delta \log_e \frac{2l}{d} \quad \therefore \delta = \frac{V}{2\pi d \log_e 2l/d}$$

Now let one of the wires A be connected to earth. The free charge on A goes to earth leaving a "bound" charge whose density is equal and opposite to that of the free charge or

$$-\delta = \frac{-V}{2\pi d \log_e 2l/d}$$

The potential of any point distance s from the wire A and due to the bound charge of density $-\delta$ is, therefore,

$$V_1 = -2\pi d\,\delta \log_e \frac{l}{s} = -\frac{V \log_e l/s}{\log_e 2l/d}$$

The resultant potential therefore at any point distant s from the axis of the wire A due to the combined actions of the charge on the cloud and the bound charge on A is

$$V + V_1 = V\left[1 - \frac{\log l/s}{\log 2l/d}\right] = V\left[1 - \frac{\log l - \log s}{\log 2l - \log d}\right]$$

This expression will give the resultant potential at the wire B when A is grounded, if we substitute in it the value $l = 20{,}000$, $d = .3648$ inches $= .0304$ feet $=$ diameter of No. 00 wire and $s = 1$ foot. Substituting these values we have

$$V + V_1 = .297\,V$$

It appears therefore from this rough calculation that if each wire of a transmission line 20,000 feet in length, the conductors of which consist of No. 00 wire, have stretched parallel to it and

at a distance of 12 inches, a grounded wire equal in size to the line wire, the potential of the line wire due to a charged cloud could not rise to exceed 30 per cent. of the value to which it would rise if the grounded wire were not present. As a matter of fact, if each of the line wires had its corresponding ground wire the potential to which they could rise would be even less than this because each line wire would be influenced not only by its own grounded wire but by all of the other grounded wires also. However, it is not usually the practice to employ a grounded wire so large as that assumed, and 12 inches is a smaller distance from grounded wire to line wire than would usually have place. The usual variation from these quantities will about compensate for the effect due to a greater number of grounded wires as usually arranged, so that the example taken serves its purpose as furnishing a criterion as to the magnitude of the effect of the grounded wires. It does not and is not intended to furnish a criterion as to construction or practical details.

Material and Dimensions of Ground Wires.

Ground wires are usually of galvanized iron. This material is probably as good from an electrical standpoint as any other, since with the rapid flow which must take place at discharge the material of the wire itself will probably make little difference in the obstruction offered to the flow. The size of the wire will have an important bearing since in general the larger the wire the less obstruction it will offer and also the greater its "shielding action." Greater effectiveness will be obtained of course for a given amount of material from a number of grounded wires of smaller size than from a smaller number of larger size. Barbed wire is often used for grounded wires but in the opinion of the writer is has no advantage over smooth wire. It seems to have been adopted with the idea that the points would in some way discharge the atmosphere, but if the accumulation of a charge on the line wires is in accordance with the explanation already given the points cannot be effective in any way.

Method of Installation.

Usually three grounded wires are installed, one on top of the pole and one on each end of a cross-arm. They are generally tied to glass insulators presumably for mechanical reasons, as all three wires are of course grounded. The wires should be grounded as often as possible, so that the obstruction to the flow between grounded wire and earth shall be kept as low as possible,

thus keeping down the direct action of the grounded wire to as low a figure as possible.

Results in Practice.

The writer has known of a number of plants where grounded wires were installed. In one of these, as the result of a number of years of operation, those in charge of the plant feel sure that the grounded wires furnish a reliable and effective protection against lightning. In some of the other plants those operating think that the grounded wires furnish more or less protection but are doubtful as to the amount. In still other plants those in charge feel sure that the grounded wires are of no value whatsoever and constitute a nuisance and menace because of their liability to break and fall across the power wires. In some of the cases of doubtful success or failure the trouble may have been due to poor grounds or to the wires not having been grounded frequently enough, as in some of these cases the wires were not grounded at every pole. In all of the doubtful cases lightning arresters which were installed in addition to the grounded wires received more or less discharges during thunder storms.

DISCUSSION OF "THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING."

PRESIDENT SCOTT:—This is certainly a very important and very interesting topic, one on which it is very difficult to secure complete and definite information. The conditions surrounding the problem are indefinite and hard to determine, as in fact are all experiments in connection with lightning work. We should be very pleased to hear from those who have had experience with this subject. I think Dr. Perrine has had something to say on this in the past.

DR. F. A. C. PERRINE:—From my own experience, I would say, that there seems to be no question but that a grounded wire on a pole line properly grounded does benefit in lightning protection. In relation to the question as to whether barbs are used or not, I agree with Mr. Mershon that they can have comparatively little effect in discharging the atmosphere, for the reason that the atmosphere that we wish to discharge is a moving atmosphere and not a stationary one. If the atmosphere were a stationary one the barbs on the wire would undoubtedly aid in the discharge. On the other hand, after a cloud has discharged in the neighborhood of the line, and the line and its accompanying guard wire has reached a stationary condition, just before the bomb charge is about to disappear from the line through the ground circuit, I believe that the points on the grounded line will tend to aid the release of the bomb charge from the power line; and while there is not much in favor of the barbs, it would be my opinion that if it is possibe to obtain a wire with a point on that is not thereby mechanically weakened, it would be advantageous to obtain such points. But such a wire is not on the market. I agree that it is not wise to fool with barbed wire, because you can get much greater permanence with simple twisted strand wire or single wire.

There is one point that has not been brought out, and that is the question of possible loss of energy due to inductance to the grounded wire. On one line that I am familiar with they claimed that there was a very serious loss of energy due to electromagnetic induction to the grounded wire, the grounded wire making short circuits parallel to the line. I made some tests on this and could not find anything that seemed to be really appreciable. I would also like to call attention, in reference to the communication that Mr. Mershon read, to the fact that the power line at Lachine, where they have found no trouble, although only protected by lightning arresters, is a line of long iron poles, where the earth-tension is undoubtedly brought nearer the line than would be the case with wooden poles. We have no practical experience except with one or two lines such as the Lachine line.

MR. MAILLOUX:—In one line in Arizona 25 miles long, which connects with a station at one end, a receiving station at the other end, and a second power station about eight miles from the

receiving end, no provision was made for lightning protection except by spark-gap lightning arresters at the stations. In other words, the line, a 3-conductor line, about 25 miles long, with transmission voltage of 22,000 volts, has only three points at which it is protected by lightning arresters. I was curious to know what had been the experience, and wrote to the operating engineer, Mr. D. W. Beldon, one of our members. He replied that the line had never been without current since it was started, last fall; that notwithstanding the fact that there had been many lightning storms, including one which occurred while the load was at its peak, there has never been any trouble at all from lightning. There is a discharge over the lightning arresters, but it has never been such as to interfere in the slightest manner with the operation of the line.

MR. A. J. WURTS:—I am pleased to note that Mr. Mershon does not recommend altogether abandoning the spark-gap lightning arrester.

I do not agree with him where he states that "this discharge will pass to earth by gradual leakage over the insulation of the system if the approach of the cloud is slow enough to give time for such leakage". I do not believe that the velocity of the cloud has any immediate influence on the static charges in overhead wires as to whether they leak to earth or become disruptive. I consider the cloud or upper storm strata and the earth to form the two terminals of a huge static machine and I think you will agree with me that a lightning discharge does not start from a single point but that the main discharge as we see it is made up of a large number of smaller tributary discharges which in turn are made up from still smaller sources, very much as our water sheds are ultimately concentrated into one large stream or river. I believe the same to be true in the earth terminal, that there also are tributary discharges from all sources of electrostatic capacity and from all directions toward the main stroke. I believe that all electric wires, grounded or otherwise, car rails, gas pipes, water pipes, all form a part of the earth terminal of this huge static machine and that a grounded wire in the neighborhood of an insulated electric line will not materially protect that line but that all will discharge alike and that the discharge will tend to be disruptive with every discharge of the static machine—with every stroke of lightning. If there is any virtue in the theory of the leakage of the static charge, surely this ought to manifest itself in our trolley wires, all of which are thoroughly well grounded as far as leakage is concerned, although for disruptive discharges it is admitted that the ground connection is of no avail, owing to the large inductive resistance intervening between the overhead wire and the ground connection.

I am sure you all know that wire fences, gas pipes, and even gilt mouldings around a room will give off discharges during a thunder storm, and these discharges, as I take it, are due to the

release of the electric stress by the lightning discharge breaking through the dielectric. The charge then which had previously existed in all bodies having electrostatic capacity, seeks to establish a path to the main lightning discharge; so that every piece of metal, every conductor, whether "grounded" or otherwise adds to the capacity of the earth terminal. I have even noticed discharges between parts of large steel buildings.

Admitting now that discharges do occur from all kinds of conductors, it would appear that the overhead grounded wire could hardly be considered a reliable source of protection because if it really did protect, I do not believe that we would obtain sparks from the inside metallic parts of buildings, protected (?) as they are by well grounded water pipes, forming the best possible overhead grounded wire.

MR. THOMAS:—I do not know of results where all the conditions have been carefully investigated and where it is definitely known that there has been trouble without a grounded wire, that it has been stopped by the addition of a grounded wire; and (to make the proof of the efficiency of a grounded wire complete) we should have also the other case, where the removal of the grounded wire shows the beginning of trouble again. Such a case would be very unlikely and in its absence we must wait for a very large number of ordinary tests.

In regard to Mr. Mershon's assumption as to the nature of the effect of lightning upon the line, he concludes that it is practically all electrostatic induction, but I believe he is hardly justified in neglecting the electromagnetic entirely.

In discharges which come to the ground in the immediate neighborhood of the line, we certainly cannot neglect the electromagnetic effects. The difficulty of protecting oil tanks and powder magazines even with a considerable amount of grounded conductor in the neighborhood is also well known.

Dr. Perrine has spoken of the losses on grounded wires close to transmission lines. I am surprised to find that it does not amount to anything. I should think it probably would be considerable, and if the grounded wire is made of considerable conducting power, *i.e.*, low ohmic resistance, I imagine there will be found quite a little loss; and more than that, if these grounded wires are placed close to the transmission line, as must be done to get effectiveness, it must considerably increase the electrostatic capacity of the system. This might be a serious item in a large plant. The problem is very complex and I think we should go very slow in staking too much on grounded wires.

Another point on which I think Mr. Hayward can give us some information—it is generally supposed that the striking of the lightning to the ground is the most harmful feature. I am inclined to believe that the discharge within the cloud in a more or less horizontal direction will produce a much more destructive effect upon a transmission line which happens to lie somewhere near parallel to the line of this discharge than a vertical discharge will.

DR. PERRINE:—I would like to speak a word, Mr. President, in explanation. I see Mr. Thomas has distorted my statement that I could not find a loss, to the statement that I found no loss. There is a good deal of difference between the two. The matter is difficult to measure. I tried to measure it, and couldn't find it. I didn't say it wasn't there.

Then there is another point that I want to call attention to now, that I think this discussion is getting a little mixed on, and that is, that there are two things to protect against. One is the gradual charge and discharge of the line due to conditions of the atmosphere, and it may be that a line is at a high potential at one part of the country and at a low potential at another, or that the line is gradually acquiring a charge from the wind blowing over the line when there is no lightning in the neighborhood, and in perfectly clear weather you can have that. It is against this form of trouble that I believe that the guard wire is of most advantage. I do not believe that the guard wire is of any very great advantage when you have lightning discharges of severe character. There you do get, as both Mr. Wurts and Mr. Thomas have stated, an electromagnetic effect as well as electrostatic; but the gradual charge and discharge of a line that would come in perfectly clear weather is a very nasty thing, and, as I said, one line that I saw myself, 46 miles long, which Mr. Mason was handling with me, was the only line, as Mr. Mason remarked, that he ever succeeded in taking hold of when there was no dynamo connected with it, in dry weather, without getting a shock. He attributed that almost entirely to the protection of the neighboring grounded wire.

DR. A. E. KENNELLY:—This is a very interesting and important subject and one that must always be of great practical consequence, because it is one of the standing difficulties in our transmission line work. We can protect against the regular difficulties, but lightning is one of the difficulties that cannot be reckoned with. Experience in this matter extends to a much earlier date than is generally supposed, because in a certain sense we have experience on this question for at least 50 years, in the protection of telegraph and telephone wires. It is true that the effects of lightning in telegraphy are of much less consequence than in a power transmission system, because the amount of property that may be damaged in telegraphy by a lightning stroke is comparatively small. Nevertheless, the experience which can be accumulated on the long wires in telegraphy bears upon the experience which we seek to accumulate in the protection of transmission lines. It has been a popular impression derived from many years experience in telegraphy that the presence of neighboring overhead wires does protect against indirect lightning effects. Of course, we know that when we speak of the direct flash nothing can afford protection, but in regard to these surges due to lightning discharges in the vicinity, there is a strong popular belief among telegraphists, that neigh-

boring wires do protect. If we know anything at all about lightning—and we do not know very much—it is that when we put a conductor wire under ground, or in an electrical conducting shell, that the buried wire is freed from electrostatic disturbances, and also, to a certain extent, freed from electromagnetic disturbances. We all believe that a buried wire, disconnected from all apparatus, is in no danger of a lightning stroke, induced or otherwise. When grounded wires are carried over and above, or in the neighborhood of, a working wire, the earth is virtually raised over that wire, or in the vicinity of that wire, and we partially produce that effect which a completely buried wire more thoroughly attains. I think, therefore, it stands to reason, that if only there are grounded wires enough over and above and around a working wire, immunity from indirect lightning surges is brought to that wire. But whether it is worth while incurring the expense and trouble of stringing the grounded wires around the working wire is another and a different question. Some years ago I had occasion to collect some information of this character from the representatives of local stations, and I found the evidence was somewhat in favor of protection by means of guard wires suspended in the neighborhood of the working wires.

The question of electrostatic capacity and its increase due to grounded wires on the working wires, is one of the minor considerations to be taken into account, but after there are three wires up in a three-phase overhead system, the extra capacity that can be given by adding other wires is comparatively trivial. It is the first extra wire that counts, and when you have several wires up together side-by-side it would not seem that the electrostatic difficulty is going to be a serious one. The amount of energy which may be wasted, in transformer fashion, from the main line to the loops of the grounded lines as secondary circuits, is also a matter to be considered, and I do not think that it has been worked out. It would seem, therefore, that there is an advantage, theoretically at least, in having grounded wires around working wires, but the disadvantage of having to string extra wires around a transmission system is very serious.

MR. LINCOLN:—Mention has been made of the electromagnetic as well as the electrostatic effect. I wish to call attention to the fact that these grounded wires are to a certain extent a protection against electromagnetic as well as electrostatic effect of a lightning discharge in the neighborhood of the transmission line. The grounded wires constitute a short-circuited secondary and the induced effects from the lightning discharge in the neighborhood will be largely absorbed by that short-circuited secondary. In a solid metallic conductor you can get no electromagnetic effect; so the ground wires may approach that condition.

One other point which has been brought out before, is in regard to the discharge by the grounded wires of the atmosphere which blows across the line. Mr. Mershon does not treat of that in his contribution, but I think it is an important point. In this

climate we do not get that effect so much as in the West, because the atmosphere here contains much more moisture.

MR. F. S. WOODWARD:—I would like to speak of just one practical point in regard to barbed wires on a line that I am familiar with. For about two years after erection they remained in good condition, then began a series of breaks due to rusting. Nearly every break of a barb wire was followed by a short circuit in line wires. As result of this experience the barb wires were replaced with No. 4 B. & S. iron wires. The extra cost of larger size iron wires was more than offset by lesser cost of erecting.

This line had ground wires every six poles. The ground wires were brought about half-way up the pole and then divided, passing up at extreme end of cross-arms. This to some extent protected linemen when at work, as otherwise they were in contact with the ground return.

MR. RUSHMORE:—There is one point which I have not heard mentioned. If a transmission line runs through a mountainous country where a considerable difference in altitude exists between different parts of the line, there will be an electrical effect, due apparently to the difference in altitude which causes a much greater difference of potential between wires and ground in the low than in the high altitudes. In some instances it is known that a considerable difference of potential exists between the base and summit of mountains. A grounded wire strung along the line should be of assistance in the prevention of trouble from this cause.

MR. R. S. KELSCH:—The Lachine Rapids Hydraulic and Land Co., Ltd., of Montreal, Can., operating a general overhead distributing system for light and power work, at 2200 volts three-phase, has experienced considerable trouble and suffered damage to transformers principally, from lightning.

When this company began operating, there were five telegraph, telephone and electric light companies operating in the city of Montreal—which compelled the Lachine Rapids Company to construct 95 per cent. of their lines below the lines of other companies. A careful record kept of the eighteen circuits indicated that the greatest amount of trouble, such as transformer burn-outs, etc., caused by lightning, occurred on the circuits that were built under the lines of other companies. When this record was started, it was supposed that the circuits running into the open districts where there were no wires above them, would show the greatest number of transformer burn-outs, etc., but the result was just the reverse.

MR. JOHN F. KELLY:—I believe that the main protective effect of the grounded wire is not against lightning discharges, but principally against the ordinary atmospheric electricity. We all know that with a difference of a few yards in elevation we may find a difference of several thousand volts, and a wire suspended at any distance above the earth will in time gain the same potential as the air or bring the air to its potential. The charge so

accumulated on a wire will discharge to earth when the conditions are favorable, the most favorable place being usually determined by the weaknesses in transformers and dynamos. As to the accumulation of that charge, the rate at which it accumulates, I remember in the old telegraph days, before the dynamo service was much developed, in western New Jersey, in the hill country there ran a telegraph line through a tunnel, and was protected by lightning arresters. Well, they couldn't put in lightning arresters fast enough 20 years ago to keep that line in service. There was trouble in calm weather, when there was no sign of disturbance in the neighborhood at all. Then, when the alternating current service was first introduced, I remember watching a line in the hills of Connecticnt. The sparking on the lightning arresters was constant on account of the atmospheric charge even in fine weather, although the line was only a few miles long. The circuit-breaker, in connection with the lightning arrester, was high chattering all the time. Now, I think it is against electricity of that nature that the grounded wire is of service, if it is of any service at all.

The most important point in Mr. Mershon's paper, to my mind, is that, if his theory is correct, the grounded wire may be placed below and yet be equally as protective as if placed above. No one heretofore has attributed any protective effect to the grounded wires when below the working conductors. The great danger in even laying it heretofore has been, that being above, in breaking, it would fall on the transmission wires.

But as to how much protective effect it really has, I think there is considerable doubt. Mr. Mershon has referred to one line on which it appears to protect perfectly. I think I recognize the line, and on that line there are a lot of water crossings, the ærial line at each crossing being replaced by a sub-aqueous cable, and at each of these crossings both sides are protected by lightning arresters. So that is one thing. The other thing is difference in elevation between the two ends of the line. The effect of hilly country, to which Mr. Rushmore alluded, is not very pronounced there. And the third thing is that they never have run without the grounded wire. On the other hand, I know of a plant in the south where they have put in grounded wires and then grounded them as often as they could. It is, however, a pretty bad country to obtain good grounds in as the clay soil takes hold deep down in the dry season. A number of the grounds have been made in water courses and some have been kept artificially wet, but I think they have not been able to find any improvement whatever. My own feeling is that while there is some protective effect from the grounded wire, that it doesn't pay for the complications.

It has been said that the electrostatic effect on the working conductors is of no importance, but I think when you get lines 150 or 200 miles long with a very high voltage and ordinary frequencies, it becomes highly important, especially if one uses

a single grounded wire not set in neutral position. I have never seen a grounded wire so placed. If it is set out of the neutral position it will affect not only the amount of electrostatic line charge but it will affect its distribution, so that the flow will be different on the three legs of the line. The disturbing effects of a balanced electrostatic charge are bad enough.

In the seventh edition of Culley's Handbook of Practical Telegraphy, p. 126, the use of individual ground wires on the poles, not connected by an overhead conductor, is described. Several able telegraph engineers have told me that this type of line construction has given them the same protection in nature and amount that the overhead grounded conductor is said to afford. Obviously, Mr. Mershon's condenser theory cannot apply here, and in consequence, these observations tend to throw doubt on the completeness of the theory.

MR. HAYWARD:—I wish to suggest to the Committee on High-Tension Transmission, that they send out word to every operating engineer, to everybody who has any stations or high-tension lines under his charge, and ask that every one of their engineers operating under them be made an observer; to have everybody working under them make careful observations, not only when the storm is on but when the storm is coming, as to what happens—time it as nearly as possible, record it in a log book. In the case of a breakdown from lightning, let him go right to the spot as if it were a fire, and let him collect the evidence right then and there, and at the end of a year or two we shall all know far much more about this lightning question than we know to-day.

I think that the location, other than the elevation—the nature of the ground—has a great deal to do with lightning discharges. I think where you have a broad valley and your lines are lying in the valley near the base of a mountain, that you will get discharges which on the average are quite different.

Our system embraces 20,000 volts and some 400 or 500 miles of high-tension circuit spreading over a country that is about 150 miles long. Starting in the old days when the insulation was low, with 2000 volts, when all the wires were in the trees, we never knew any lightning trouble in any shape. As we improved our installation our lightning troubles came on us more and more, and now, carrying 20,000 volts, with lines thoroughly insulated, we know what lightning means. I do think that overhead grounded wires, such as telephone and telegraph wires, are a protection, for this reason, that I have never lost a transformer in our business section which is the most thickly covered with other wires. But they are not complete protection by any means, even at 2,000 volts, for although our lines at Salt Lake City are almost all on the same poles as the telephone wires, yet the telephone wires do not entirely protect them. At the same time, we cannot help feeling that if you absolutely surround your wires with a grounded network, that they must be protected, except against perhaps

some great stroke of lightning, so to speak. However, that is absolutely impracticable from our point of view. We have had many and many an instance where there has been a sudden discharge of lightning, and almost instantaneously, or immediately following, there has been a jump from the lead outside the transformer to the case of the transformer, rather than going through the transformer-coil. We have had a lightning discharge smash up the insulators on the line, cut into the station, jump from the lead coming from a transformer from 16,000 volts, cut off the transformer and the puncture papers in the lightning arresters never show any discharge. Now, all those occurrences which we have all show the same sort of effect. Our troubles come at the moment when the lightning discharges. Troubles due to the raising of the potential of the line when there is a dust storm, or wind storm or a thunder cloud, are taken care of on the lightning arrester. I have never heard or known of any trouble from that. Every single occurrence that has ever given us any trouble has been at the moment of the lightning discharge.

MR. JOHN F. KELLY:—Mr. Hayward, I think, is probably right as to his having no trouble on very high-tension lines from atmospheric electricity, but the conditions are very different on lines of moderate-tension or low-tension, like telegraph wires. On a high-tension line the voltage with which one is sealing on the line is itself of a magnitude comparable with the atmospheric difference of potential discharge, and consequently when the dielectric strength is made sufficient to resist the puncturing of the insulating material, puncture by the charge accumulated by the wires is also presumably guarded against. But on low-tension circuits, where the normal voltage is much below the difference of potential that may arise from atmospheric charge, there is no such guard against atmospheric effects.

PRESIDENT SCOTT:—Mr. Hayward has the difficulties which come to engineers through coöperation. He is trying to coöperate some three or four different plants in different places and in different directions from Salt Lake City, and which have been laid out with different voltages and under different conditions, as separate independent plants entirely,—the old Pioneer plant at Ogden, the Utah Power Company, the big Cottonwood, and now, I believe, he is linked in with the Telluride Power Transmission Company. Is there any further discussion?

MR. W. S. WATERS:—I did not quite follow Mr. Mershon's theoretical calculation, but I would like to suggest an alternative calculation, which has the advantage, from my point of view, that gives results which agree more with my own practical experience.

Let us assume that a cloud has just discharged, and that we are left with an induced charge on the transmission wire which raises this wire to a high potential above the earth, and we wish to find out to what extent the presence of a grounded wire will lower this potential. The system which we have to consider

consists of the transmission wire B, carrying a charge Q_1, the grounded wire A, carrying an induced charge Q_2, and the earth G, also carrying an induced charge. For the purpose of calculation, the earth can be considered an as infinite conducting plane, and by Lord Kelvin's theory of electirc images the distribution of electricity induced on the surface of the earth can be replaced by charges $-Q_1$ at C, which is the image of B, and $-Q_2$ at D, which is the image of A. Then we have for the potential of wire A

$$V_2 = p_{ab} Q_1 + p_{aa} Q_2 - p_{ac} Q_1 - p_{ad} Q_2 \tag{1}$$

where p_{ab}, p_{ac}, etc., are Maxwell's coefficients of potential. And assuming that the diameter of the wires is infinitely small compared to the distance between them, these are given by the expression,

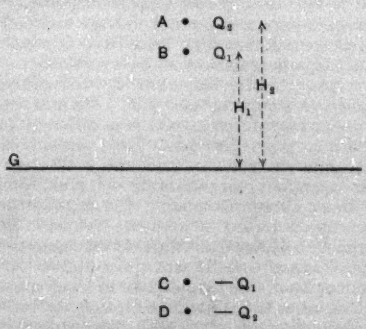
$$p = -2 \log r$$

where r is the distance from the center of one wire to the center of the other.

But as the wire A is grounded its potential V_2 is zero. Thus putting $V_2 = 0$ in equation (1) and solving for Q_2 we get

$$Q_2 = Q_1 \frac{\log \dfrac{H_2 - H_1}{H_2 + H_1}}{\log \dfrac{4\ H_2}{d}}$$

where d is the diameter of the wires.



Similarly, we have for V_1 the potential of the transmission wire B.

$$V_1 = p_{bb} Q_1 + p_{ab} Q_2 - p_{bc} Q_1 - p_{bd} Q_2$$

substituting for Q_2 in terms of Q_1, and evaluating we get:

$$V_1 = 2\,Q_1 \left\{ \log \frac{4\,H_1}{d} - \frac{\left(\log \frac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \frac{4\,H_2}{d}} \right\}$$

Assuming the ground wire not present this becomes:

$$\overline{V_1} = 2Q_1 \log \frac{4\,H_1}{d}$$

so we get as the value for the shielding effect:

$$\frac{\overline{V_1} - V_1}{\overline{V_1}} = \frac{\left(\log \frac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \frac{4\,H_2}{d} \cdot \log \frac{4\,H_1}{d}}$$

Taking the numerical value used by Mr. Mershon, *i.e.*, No. 00 wires 12 inches apart, and taking the height above the ground as 30 feet, we get the shielding to be 25 per cent. Taking what perhaps is a more practical case, No. 4 wires 24 inches apart, we get the shielding to be 14 per cent., which is rather different from Mr. Mershon's result.

But I think that a theoretical discussion of this subject is not very much to the point, because we really know very little about the conditions in the phenomena which we are discussing. It is also extremely difficult to get any reliable practical information as regards the effect of the ground wire because unless we do as Mr. Thomas has suggested, *i.e.*, try a number of transmission lines both with and without a ground wire, we cannot really get any definite information. The fact that one transmission line is satisfactory without a ground wire and a second one is also satisfactory with a ground wire gives us no really definite information.

My own experience has been confined to European conditions, *i.e.*, short mountain lines worked at 5,000 to 10,000 volts. The conditions under which they work are violent lightning storms, and heavy sleet and snow storms during certain seasons of the year. The sleet and snow storms very often bring down the ground wire, producing a short circuit, and the screening effect of the ground wire does not seem to be very appreciable in a lighting storm. So that the general opinion of operating engineers is that the ground wire is far more trouble than it is worth.

MR. CURTIS:—In this discussion I notice that several gentlemen have referred to the failure of telephone lines located above power leads to protect the latter from lightning or electrostatic induction. When we take into consideration the fact that modern telephone lines are composed of metallic circuits almost exclusively and are not grounded, their failure in this respect

hardly seems strange, and further if they actually *do* afford the slightest shielding action it must be accounted for by some other theory than that pertaining to grounded wires. I believe the same statement is practically true of telegraph circuits, which are rounded normally only at their extremities, which would render them ineffective owing to conductor resistance, except for exceedingly short distances from their terminals. I have known long metallic telephone circuits, with clear weather prevailing their entire length and breadth, to give off electrostatic discharges sufficiently severe to destroy the coils connected to them, the current of course seeking the shortest path to ground.

PROFESSOR D. C. JACKSON:—The problem which exists with respect to protecting a line from sparking to ground or surrounding parts, no matter what the cause, is to keep the line as nearly as possible at the same electrostatic potential as the ground. Now undoubtedly the grounded guard wire does something in that direction, and Mr. Mershon is right in making his computation and saying that there is some effect from the guard wire; but on the other hand, he has not taken data of such a form and of such numerical values as to give results that may be considered to be always applicable, or adaptable to commercial conditions in a long and important transmission line. For instance, the guard wire in Mr. Mershon's example is taken too close to the line wire, and since the protective effect is dependent upon the logarithm, as the guard wire gets farther away from the line the falling off of the protection is enormously rapid. I therefore think Mr. Mershon is misleading us by taking his one foot distance; he is exaggerating the effect.

There is another element that Mr. Mershon has omitted, which has a great deal of influence. You must bear in mind that if one has an induced discharge upon a tranmsission line and guard wire due to a cloud overhead, and that cloud discharges into a cloud at some distance, or discharges to earth, there is an almost *instantaneous* change of the potential of the earth under the line at certain points and also of the atmosphere surrounding the guard wire. The resistance of the guard wire, its inductance and capacity enter to modify the instantaneous change of the charge in the guard wire itself and consequently the guard wire during this period (because of resistance, self-inductance and capacity), is unable to exert its full influence to protect the line wire; and Mr. Mershon has omitted to introduce the effects of the self inductance and capacity and resistance of the guard wire and its ground connections into his formula. I think that he has omitted them because they cannot yet be put in, for the reason that we do not have a reasonable knowledge of their values under the conditions and therefore have no way of representing them in the formulas. So I say Mr. Mershon is right in presenting the matter as he has, but he is without question exaggerating the effect of the guard wires, and very largely exaggerating it, when he says that it may be expected to afford a protection of some-

thing like 70 per cent. I think if this was taken at 7 per cent. or 7/10 of 1 per cent., it perhaps would come nearer the truth.

MR. MERSHON:—I think that in general I agree with Professor Jackson—but I would like to take up one or two points in connection with what he has said.

As regards the theory of the matter, I agree pretty thoroughly with Professor Jackson. I will not commit myself too far, however, in that regard. As regards what Mr. Waters has said, I made an assumption in treating this matter, on purpose to keep the problem simple. I assumed that the space potential at each of the two wires was the same. I think if the wires are in the same horizontal plane it is a pretty fair assumption, and this is the relative position which most frequently has place in practice.

As regards the size and distance between wires, I am not so very far wrong. If I remember rightly, the distance I have taken as between the wires is exactly that which existed on a line on which it was claimed the ground wou'd give very good protection. The size, also, was approximately that which I have taken; for barbed wire was used whose effective size, because of the twisted strands, is considerably greater than a single wire of an equivalent section. For most cases in practice I think the figures I have given furnish a fair sort of criterion. I have purposely avoided the questions of oscillatory effect, of self-induction and all those complicated questions which require elaborate assumptions of questionable accuracy.

It seems to me that the question of electromagnetic action is one of amperes and frequency, and not of volts, as Mr. Thomas has stated, and it is hardly conceivable to me that the currents at the distances that flashes often occur would be great enough to affect the line seriously from electromagnetic action.

Now, as regards the position of the cloud, that changes the problem to some extent, but I do not think it changes it altogether. The shielding action, even if the cloud is affecting only part of the line, would have place to a considerable extent.

As regards the discharge of the atmosphere itself—suppose the particles of air or moisture around the wire are charged, isn't it likely that the effect of the inductive action due to the great mass of particles beyond the wire will be considerably greater than that of simple leakage from those particles to the wire, if there is such a leakage effect? The flash between clouds, it seems to me, does not alter the problem so very materially. You have the effect there of a redistribution of charge, and you still have to a considerable extent the shielding action of the grounded wire.

As regards the difference in altitude, I have gotten the altitude effects in a great many cases and it never seemed to me necessary to explain them by leakage from the atmosphere. Simply because you cannot see a cloud, is no proof that it does not exist. The cloud need not necessarily be a mass of moisture; it may be air under some condition differing from that of the surrounding air; so that in considering a charged cloud, we should

consider any mass, whether it be moisture or whether it be air of a different density from the air around it, and which might accumulate a charge on the surface of separation between it and the surrounding air.

As regards protection from electromagnetic effects, if there are any, the resistance of the ordinary grounded wire would be too high, and the self-induction too high, to furnish much protection, especially as you cannot conveniently ground the wire any oftener than at each pole.

As regards the gathering of data, the grounded wire is taken up in the lists which the Transmission Committee are sending out, many of which are coming back filled in. We should be only too glad to get the minute attention to the subject of lightning protection, as well as other points taken up by these lists, that Mr. Hayward advocates, and we shall certainly expect to get a fine lot of data from Mr. Hayward's plants.

MR. W. J. HAMMER:—Last Fall I had the pleasure of spending some days investigating the Valtellina 20,000 volt, 3-phase Railroad in Italy constructed by Messrs. Ganz & Co., of Budapest, Hungary.

I remember that one of the methods of protection used was a drain pipe filled with water, which acted as a water resistance, and which was connected to the wires and to the ground, the intention being that while there would be ordinarily no leakage, when lightning passed over the circuit these would act as a protective device. The main reliance, however, was placed on a form of lightning arrester which by its simplicity commended itself strongly to me. I understand that since these have been put in place no lightning has ever entered the power house, and it is claimed that there is no necessity for lightning arresters inside of the power house.

The device, which was placed just outside of the power-house, consisted of three funnels, one attached to each of the 3-phase circuits, being supported by porcelain insulators. Underneath each funnel is a little spray of water which is thrown up so that it is a short distance from the funnel, but not making contact therewith. Should any abnormal voltage appear on the line due to lightning it is carried off by the jets of water.

MR. W. A. BLANCK:—I will state that in most of the Italian and German high-tension lines lightning arresters are used only in power stations and substations and seldom on the line itself. The use of iron such as barbed wire along the line for protection of the same from lightning has been abandoned.

The lightning arresters mentioned by Mr. Hammer are used on the Valtellina Railroad in northern Italy and consist of a small reservoir which furnishes constantly dripping water to the various wires of the high tension system. The small drops of water upon reaching the wires are charged and upon leaving them carry off this charge and in this way very satisfactory results are obtained.

MR. MERSHON:—I would like to hear from Dr. Perrine and some of the other members who have spoken of the losses due to a grounded wire as to how that loss could occur and as to the nature of it. Do they mean atmospheric loss? It seems to me that with grounded wires, especially if the neutral of your system is grounded and you have between the grounded wires and the line wires anything like the distance there is between line wires themselves, you will not get much loss. For you are then concerned with a voltage a great deal lower than that between the line wires and you presumably keep the atmospheric loss between them pretty well down.

MR. MAILLOUX:—I want to caution Mr. Mershon, in his statement about the loss due to electromagnetic effect caused in the parasitic circuits, constituted by the grounded sections. He says that the resistance of these segments would be a protection against loss. I think that there is a certain resistance at which that loss will be the maximum. If we have an infinitely great resistance, of course we would have an e.m.f. there, but no current. With an infinitely small resistance we would have a reactance loop in which you would have a full counter e.m.f. effect and very little loss excepting the small $I^2 R$ loss necessary to keep the large current flowing; but there is between those extremes a critical resistance which corresponds to the maximum loss. Evidently, we only have a differential e.m.f. due to the difference between the electromagnetic effects of the three wires. If the conducting wire could be placed in the center of the triangle perhaps the resultant effect would be negligable any way.

PRESIDENT SCOTT:—The paper we will take up now is: "On the Testing of Electrical Apparatus for Dielectric Strength," by P. H. Thomas.

To be presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

THE TESTING OF ELECTRICAL APPARATUS FOR DIELECTRIC STRENGTH.

BY P. H. THOMAS.

It is evidently very desirable before depending upon apparatus for commercial service, to have assurance that it is in proper operating condition and also, where the apparatus is built to specification, that the specification has been met. The only practical method of determining the condition of the apparatus as regards its insulation is by means of over-potential tests. *Potential tests have been used for a number of years and have been found to be in general quite satisfactory.* However, in common with all types of tests which depend upon the application of abnormal strains, over potential tests have certain drawbacks and involve certain risks. A brief discussion of such objections, especially in regard to insulation tests upon very high tension apparatus, will be found in the following pages.

(1) A disruptive test fails partially of its object in testing the fitness of the apparatus for actual service, because the conditions of the test do not approximate closely the conditions of the service, either normal or emergency conditions.

(2) Serious injury may be done to the insulation of the apparatus by the test, even under apparently favorable conditions, so that failure may result afterwards in actual service.

(3) In making tests on finished apparatus, it is impossible to test each portion of the insulation separately and the result of many types and forms of insulation being coupled together, is that only that which is weakest with regard to the particular conditions existing at time of test will be tested.

(4) In general, electrical apparatus is never in a condition so poorly adapted to stand dielectric strains as when first installed.

(5) Insulation tests require special testing apparatus and expert and *experienced* direction which are very often not available, and without which great risk is run in attempting such tests.

(6) As an exception to the above (paragraph 5) it is evident that some simple types of apparatus, such as insulators, high tension bus bar insulation, high tension series transformers, etc., may be readily tested without great danger.

(7) Fuller consideration of paragraph (1.) Potential strains upon dielectrics cause effects of two kinds:

(*a*) A constant tendency to puncture the dielectric, which is caused directly by the presence of the potential and depends on the physical dimensions and nature of the dielectric, and which probably remains constant as long as conditions are unchanged; *e g.*, physical or chemical state. This strain is almost mechanical in its nature.

(*b*) A tendency to heat or produce chemical change in the dielectric, largely the former. This heating also is caused by the voltage and is very much more marked with alternating current than with direct current. Though comparatively small in actual amount, this generation of heat is a dangerous thing, as it occurs within the body of the insulating material which is usually a poor conductor of heat.

As insulation heats up, it becomes much less able to withstand the strain described in paragraph (*a*) above, and, further, the rate of generation of heat within the insulation itself becomes much greater. As a net result, if insulation under strain once reaches a sufficiently high temperature, it is practically certain to get hotter and hotter and ultimately to break down. In other words, for continuous running it is necessary that the heat generated by the potential in the dielectric be dissipated as fast as generated. In tests of actual apparatus, the critical rise of temperature may be reached in as short a time as one-tenth of a second in some cases, or in other cases perhaps only after a long time, perhaps an hour. As long a time as an hour would be required only in large bodies of insulating material; *e.g.*, in large capacity or high-tension apparatus.

Different kinds of insulating material are affected by the strains described under (*a*) and (*b*) in very different degrees. Gaseous dielectrics suffer substantially no heating, while solids and liquids usually have their breaking-down strength determined by this heat factor.

In actual service, injuries to electrical apparatus usually result from overheating, dirt, moisture, chemical exposure, mechanical injury or wear due to vibration and occasionally a strain from lightning or over-potential stress. The latter strains, however, are rarely extremely severe, except as they may cause local concentration of potential in the windings of apparatus, as will be discussed later.

Thus the voltage time test, which is usually applied to finished electric apparatus, by no means reproduces all the conditions of actual service On the other hand, it is of course true that apparatus which will stand a high disruptive test will usually stand better in service, so that such a test is of value.

If a high disruptive test is relied upon by a purchaser to determine the acceptance of apparatus and to terminate responsibility on the part of the manufacturer, the latter will be tempted to design his insulation in such a manner as best to stand the disruptive test at the sacrifice of some features more valuable for preventing deterioration in actual service. This difficulty becomes a very serious one where unusually severe disruptive tests are specified in a contract.

(8) Fuller consideration of paragraph (2.) With low-tension apparatus, little or no harm is to be expected from reasonable over-potential tests carefully made, provided insulation is in good condition. An exception should perhaps be made of dangers of local concentration of strain in high tension generators or motors of small size, as will be explained later. The following discussion applies to high tension apparatus chiefly.

The amount of heat generated within the body of a dielectric increases at least as fast as the square of the voltage. Further, this loss, with constant voltage, may be increased several times by an increase of 100° C. in temperature. This means that a strain of double potential continued for any length of time strains the solid insulating material far beyond any condition it will meet in service. Further, the ability to stand the strain will be determined rather by the facility for getting rid of the heat, which is usually of little consequence in commercial work than by other features of the insulation more desirable for actual service; further, the hottest part of the insulation will be inside, so that the center portion of the material may be badly charred, while the outer portion, the only part visible to the eye, has been kept cool and appears uninjured. This means that very serious injury to high tension apparatus may be entirely beyond the

possibility of detection until further developed by actual service.

Potential strains above a certain critical point cause a tendency for brush discharge over any insulating surface. If continued, this will deteriorate the insulation so that a discharge may continue afterwards at a lower voltage. This effect will occur even under oil and, like the internal heat, will not be visible to the eye until in a very advanced stage.

When a coil is charged to a high potential and one end is suddenly discharged, there is a strain equal as a maximum to the full value of the discharge voltage, tending to cause the charge upon the turns of the coil to jump to the terminal through the insulation across the turns rather than pass around these turns. Since this total "discharge voltage" may be the abnormal voltage at which the apparatus is being tested and since this abnormal strain may be concentrated on a portion of one coil, where many coils are used to withstand the normal voltage of the circuit, it is evident that certain turns of the coil (which lie next to the terminal which is being discharged) will receive excessive strain. The condition which is essential to produce this concentration is that the discharge of the terminal of the coil shall be extremely sudden. This can usually occur only when the terminal is discharged by a spark close to the terminal itself, electrically speaking, *e.g.*: any accidental or other discharge between the wires used in applying the test, or in the apparatus itself, will tend to puncture insulation between turns at certain points within the winding. Such injury will oftentimes not be discovered, as the apparatus being tested is not in a condition to show a short circuit when it is not connected to a generator. This danger is very serious with extremely high voltages. Apparatus may be protected against this strain by the use of choke coils, or high resistances, or static interrupters in the leads of the apparatus to be protected, provided no discharge occurs nearer the apparatus than the protective device. In this connection it should be noted that if the spark gap is used as an auxiliary to measure the potential of the test, satisfactory means must be used to prevent a discharge on the spark gap from causing injury to the apparatus being tested.

The emphasis placed upon this particular phenomenon is not for theoretical reasons only, but because, in a number of actual cases, serious injury has resulted to apparatus therefrom. Furthermore, such conditions have been reproduced for purposes of investigation.

(9) Fuller consideration of paragraph (3).

In testing finished apparatus, it is manifestly impracticable to subdivide the windings into more than a very limited number of parts, *e.g.*: in case of the transformer, into more than possibly four parts. When such a portion is subjected to disruptive test, a breakdown may evidently occur in a number of ways, *e.g.*: between portions insulated only by air distances; over a surface of insulating material, which may be marble on terminal block, fibrous material or possibly the surface of oil in an oil insulated piece of apparatus. Furthermore, breakdown may occur through solid material, which in some places will be well ventilated and in other places will not be well ventilated. Sometimes portions of this material which in the disruptive test receives full strain, may when running in commercial service be so located as practically to receive a very much less strain. Such a point, for instance, would be the neutral point of a three phase, star wound generator. It is thus clear that if the severity of a test (as it must necessarily be) is determined by the strength of the insulation of the weakest spot of these various types and qualities of insulation, the other parts will receive an insufficient test. It may occur that a portion of the insulation less likely to give trouble in subsequent service will be this weakest portion, and will determine the whole test, leaving the condition of the other more vital portions of the insulation insufficiently tested.

(10) Fuller discussion of paragraph (5).

In tests made by persons inexperienced in such matters, there is grave danger of injury to apparatus which would not result when tests are properly made. Such difficulty may arise by the use of testing apparatus having too high an inductive factor or field reaction, so that current to the apparatus may either raise the voltage beyond the usual ratio or so deform the e.m.f. wave as to cause an excessive strain; or by making tests when insulation is not in good condition; or in preliminary trials, in allowing tests to be on too long, though perhaps at a slightly lower voltage than the voltage of final test; or by improperly determining the temperature of the apparatus; or in a number of other ways unnecessary to enumerate. Difficulty from this source is by no means of rare occurrence, and it is very difficult to avoid in large high tension apparatus.

(11) Precautions to be observed in testing.

The most important precautions to be observed in making disruptive tests are here summarized:

(*a*) Insulation of all apparatus to be tested should be definitely known to be thoroughly dry.

(*b*) All insulation surfaces and the apparatus in general should be clean and free from all kinds of foreign matter.

(*c*) The measurement of the insulation resistance will sometimes give an idea of the fitness of the insulation for test. This condition will usually be determined not by the absolute value of the insulation resistance, but by a curve of the variation of insulation resistance as the apparatus is being dried out. When it has been increasing for a period and finally becomes steady with steady temperature, the drying operation is probably fairly complete. *However, where air or oil spaces are included in the bulk of the insulating parts, these spaces may determine the insulation resistance so that no indication is given of the condition of the actual solid material.*

(*d*) Before applying a disruptive test, it should be definitely determined that the temperature of no part of the apparatus to be tested is above that at which the test is to be made, remembering that tests of apparatus when hot, especially when very hot, are extremely severe.

(*e*) Electrical apparatus of large capacity, which necessarily contains considerable masses of iron and copper, lags behind the atmosphere in temperature changes, consequently when the atmosphere is damp and warmer than the apparatus, there is a tendency for the latter to " sweat " or condense moisture upon its surface. This moisture will at least partially be absorbed by the insulation material and render the apparatus unfit for test; consequently, it is important in unpacking to open the packing case only when the air is cooler than the apparatus. *In case of oil-insulated apparatus, the insulation must be protected from moisture when once dried out until immersed ready for service.*

(f) The determination of the high-tension voltage actually reached during test is sometimes a difficult matter. The things to be avoided chiefly are the distortion of wave form or the change in ratio of transforming apparatus, or excessive drop due to the use of apparatus for applying the testing voltage, which is of insufficient size to supply the charging energy required by the apparatus to be tested. This subject deserves a full consideration, but has been so fully discussed elsewhere that further space will not be given here.

(*g*) In applying the potential of test to apparatus, the voltage should not be raised on the testing set to full value and then

applied to the apparatus, but after being connected to the apparatus should be increased rapidly by small steps, or continuously from a voltage not over one-half the final value. Also, the voltage should be raised so quickly that the time during which the last 10 per cent. or 20 per cent. of the voltage is being applied will be short, as compared with the prescribed duration of the full potential test.

(*h*) To prevent local concentration of potential which results from any spark or break down occurring near the apparatus to be tested when the latter contains coils; choke-coils, static interrupters, or resistance in series with the terminal of the apparatus to be tested may be used. The result essential to the avoidance of this local strain is the prevention of the strain caused by the above mentioned breakdown from being transmitted without being smoothed out to the windings under test.

Evidently a choke coil in the lead of the apparatus will allow a change of potential to pass through it only slowly and if this coil be made to have several times the choking effect of the smallest portion of the winding to be protected (next the terminal) which is considered to be able to stand the voltage of the test momentarily, the necessary protection will be obtained. It would seem that a resistance in the place of the choke-coil would serve the same purpose and in a measure it undoubtedly will. However, since the resistance does not absorb voltage until after considerable current strength has been attained, it is not as well adapted to protect from sudden changes of potential as the choke-coil. The static interrupter being merely a choke-coil whose power is increased by the use of the condenser, will act in the same manner as the choke-coil described above. Usually, however, except where static interrupters are provided for other purposes, the choke-coil will be found more convenient.

(12) No complete recommendations are here made for specifications for testing apparatus for dielectric strength, but a few suggestions will be offered on topics in which there is probably a considerable diversity of opinion.

(*a*) In high-tension apparatus, *e.g.*: 20,000 volts and above, only moderate, short time, over voltage tests should be specified in contracts.

(*b*) Such tests should be made once for all when the apparatus is known to be in good condition, preferably at the factory, by experts, to give assurance that the specification has been met. Such tests should not be made a second time.

(*c*) After installation, a considerably lesser test should be made upon the apparatus, which will detect any serious injury in transportation and installation. Any moderate deterioration due to absorption of moisture, etc., will right itself with service, provided no abnormal deterioration has occurred.

(*d*) It is preferable to make high potential tests by increasing the voltage upon the apparatus as it is designed to operate, one terminal at a time remaining grounded, rather than making a high breakdown test by voltage from an external source.

(*e*) On tests of very high-tension apparatus, such as generators and transformers, no breakdown gap should be used in connection with the determination of voltage. Any error in the voltage of test, provided precautions as to the proper size of testing apparatus are used, will be comparatively unimportant. In some cases the voltage of the testing device may be determined by means of a spark-gap before the apparatus to be tested is connected to the circuit.

It must be borne in mind that in the above discussion only the objections to over-potential tests and the dangers to apparatus involved, have been considered; and that it is not recommended that disruptive tests be abolished. Such tests may be and regularly are made successfully and are very desirable to insure good insulation in electric apparatus and to determine the fulfilment of specifications. The point it is desired to emphasize is that great care should be taken to avoid injury to apparatus and that excessively severe tests, especially long-time tests at high potential should be avoided.

MR. L. A. HAWKINS:—In regard to the use of choke coils for protective purposes in the leads between the testing set and the apparatus, although such coils are of value in preventing a destructive rush of current in case of the breaking down of the insulation of the apparatus, I do not think that their value is great as far as discharges outside of the apparatus are concerned. The testing set and the leads should be installed so that there can be no danger of an accidental discharge due to the breaking of the insulation of the testing set or leads. Consequently, unless a spark gap is used, there could be no discharges outside of the apparatus itself, in which case the choke-coils would furnish no protection beyond that furnished by resistance in preventing destructive current flow in case of a breakdown of the apparatus. I believe that the best protection against puncturing of the insulation due to sudden discharge lies in sub-dividing the winding as much as possible and short-circuiting the subdivisions by connecting both ends of each subdivision to the lead of the testing set.

I do not consider of much importance the objection raised in the paper that the weakest point is the only one tested. In practice it is the weakest point alone that is of importance. If that is strong enough to stand, the rest will take care of itself. Even in such cases as that cited, as in the coils adjacent to the neutral point in a three-phase grounded generator or transformer system, I believe that all the insulation should receive the full high-voltage test, for although under normal conditions the insulation of the parts near to the neutral point are subject to no high-voltage strain, nevertheless changing conditions of operation may necessitate a change in the connection of the apparatus, so that the part that was formerly at ground potential may receive the full line voltage.

As to the dangers introduced by the changes in voltage and wave-form in the testing set caused by the charging current, I believe that the best precaution is in employing a testing set of sufficient size relative to that of the apparatus to be tested, so that the charging current can have little effect on voltage or wave-form.

I thoroughly agree with the statement that on tests of very high-tension apparatus no spark-gap should be used in connection with the determination of the voltage. I believe that the use of a spark-gap introduces danger to the apparatus and inaccuracy in the results of the test. Especially when oil insulation is employed, if the apparatus starts to break, the spark-gap will usually break simultaneously and will maintain the arc, while the oil closes the break in the apparatus and stops it almost intanstaneously. Consequently, without very close inspection the original kick through the oil will pass unnoticed and the apparatus will appear to have withstood a potential as measured by the gap considerably higher than the actual impressed voltage under which it really broke down. On the other hand, when the spark-

gap breaks first it introduces danger to the apparatus due to the sudden rise in voltage as pointed out in the paper. If testing apparatus of sufficient capacity is used, the ratio of transformation can safely be relied upon, especially since this may be checked up before the actual test, under different conditions by means of the spark-gap.

MR. M. H. GERRY, JR.:—Tests of apparatus for dielectric strength, as well as for any other purpose, should be made under conditions approximating at least those of actual service. It is useless, and may be positively harmful, to make strength tests under conditions differing widely from those under which the apparatus will actually operate.

There can be no objection to testing under any conditions, samples of insulation which fairly represent the material as a whole, used in the construction. If anything, there should be more of such tests, and less testing under severe strains of the finished product. We do not think of testing a steel structure as a whole up to the elastic limit of the material, but rather we confine such tests to samples representing the whole, and after determining the characteristics, we ascertain from the dimensions of the various parts of the structure, whether it is safe as a whole, and conforms to the requirements.

It may be urged that we possess a lesser knowledge of the strength of insulating materials than of the physical qualities of materials of engineering construction. I doubt if this be a fact at the present day. Insulating materials possessing a very fair uniformity of strength may be obtained; samples having been tested to determine the dielectric strength, and the heating under continuously applied strain, etc., it is possible, allowing a proper factor of safety, to predetermine the amount of insulation required, with practically the same accuracy as the strength of the materials in most engineering structures. It then becomes a matter of inspection to see that the required amounts of insulation are applied in the course of construction.

Reasonable insulation tests of finished apparatus, under conditions approximating those of service, are of course of some value in detecting serious errors in construction, but they are by no means conclusive evidence that the apparatus meets all requirements.

Mr. Thomas' remarks in reference to the effect of temperature on insulating material are worthy of most careful consideration. In this connection it should be pointed out that insulation may deteriorate after leaving the factory, due either to continued heating at operating temperatures, to chemical change, to the absorption of moisture, or to other causes. Insulation designed to withstand very high dielectric strain, especially if intended to operate under oil, should be carefully handled and protected in shipment. As mentioned by Mr. Thomas, large masses of material, such as transformer cores, have a temperature lag, which tends to condense moisture under some conditions. This

is a matter of importance especially in connection with the shipment of large high-tension transformers.

MR. PECK:—I believe that apparatus should be tested under conditions which approximate as nearly as possible the actual operating conditions. Mr. Thomas advises the protection of apparatus under test by means of choke-coils or resistances inserted in the high-tension leads or in series with the spark gap where it is used for measuring voltage. These precautions are taken to prevent an abnormal concentration of voltage upon a few turns or layers of the winding when a sudden ground occurs or a spark-gap breaks down. If the apparatus while in service is to be protected by choke-coils or static interrupters, then it should be similarly protected during test; but if the apparatus is not to be so protected in service, it may be questioned whether it is legitimate to apply such protection during the test.

Mr. Thomas also advises a high test on apparatus before it is shipped, and a lower test after it is installed. The reason for this is that the insulation just after the apparatus is installed is in a weak condition due to the absorption of moisture during transit, and is not therefore in a condition to withstand severe tests.

The objection to this is that while the insulation is in bad condition, an excessive strain may occur and damage the apparatus. In fact, just after a plant has been installed when everything is new, and the men not accustomed to the methods of handling the apparatus, and the line has not been thoroughly tested, excessive strains are particularly liable to occur.

For these reasons it is my opinion that whether the apparatus is to be tested after installation or not, every precaution should be taken to put it into the best possible condition before it is placed in service.

MR. STOTT:—In regard to the testing of electrical apparatus, I think that the tendency of this paper is to discourage such things. Now, on what are we to depend for our factor of safety without an over-potential test. In all structural material for mechanical purposes we insist upon strength and we also insist upon a factor of safety ranging all the way from three to ten. Now, if we simply accept apparatus to run on normal voltage, we have absolutely no factor of safety protection. There may be one there, but we do not know it. There may be weak points developed and it is very much easier to take care of a breakdown of insulation on a test than it is in actual operation when you have a great many thousand kilowatts ready to burn it up. I think the tendency to discourage tests is distinctly against the best interests of the operating companies at all events, and therefore against the best interests of the manufacturer. Of course, there is a limit of safety beyond which a test should not be pressed, and that is a difficult point to decide, just what is that limit. I would say it should be 50 per cent. over-potential, 100 per cent. or 300 per cent.—the conditions will probably dictate just what that over-potential should be.

Reference has been made to moisture on insulation. I presume that refers more particularly to armature insulation. I have been working on some experiments recently on that subject, as far as surface leakage goes, and the experiment was carried on something after this style: A creeping surface amounting to about 4½ inches of insulation was established and the test used in an atmosphere of steam—simple atmospheric pressure saturated steam—and that steam had apparently no influence whatever upon the surface leakage. The only thing that had any influence was the presence of dirt of any description. So long as the insulation was absolutely clean, we went up from 40,000 volts on a 4½ inch surface, and had no effect whatever. So that I think that that statement as to moisture should be qualified a little. The moment dirt of any description was introduced on the surface, such as particles of oil or carbon dust, or particles of dust and oil floating in the air, then the insulation broke down immediately in the presence of moisture.

MR. LINCOLN:—Mr. Stott makes the analogy between the testing of mechanical apparatus and the testing of electrical apparatus which I think hardly holds. When you test apparatus for physical properties—iron, for instance—take a test piece out of each cast or from whatever it is desired to test, put it into the testing machine and break it. If that method were followed in testing electrical apparatus it would meet the approval of the manufacturers; to take a sample of the insulation, put it into the machine and test its insulating qualities. But when Mr. Stott buys a dynamo he doesn't strain the bed plate until he breaks it. That is somewhat analogous to the over-voltage strain on the insulation of a dynamo.

MR. STOTT:—I did not mean to apply a strain to break down insulation, but a testing strain that would guarantee that there was a factor of safety in that material.

MR. LINCOLN:—The tested part would determine that, it seems to me.

MR. STOTT:—It would not determine the workmanship, however.

MR. GANO S. DUNN:—In the latter case the test of insulation on the armature is as much to determine whether the proper thickness of insulation is present as to determine whether that insulation, being present, is of the proper strength. (Quality of insulation can be supervised but quantity at every point not so easily.) Therefore, I side with Mr. Stott in feeling that a certain degree of high potential test is necessary.

MR. THOMAS:—Gentlemen, if you will read the last paragraph of my paper you will find that I do not recommend abolishing high-tension tests. I distinctly recommend them, only that they be made reasonable.

MR. W. L. WATERS:—When the insulation is designed for any high-tension winding, the engineer who designs it knows, or should know, at what voltage that insulation will break down,

assuming that it is tried and that it is in perfect condition mechanically. What he wishes to test for afterwards is to find out whether the insulation was damaged during manufacture or during transit.

The usual experience in the testing room is that if the insulation of a machine is going to break down on the high voltage test, it will do so during the first few seconds during which the high potential is applied. The reason for this is that if the insulation is damaged at all, it is usually totally ruined in certain places, so that it breaks down almost as soon as the high potential is applied. So I think that a more satisfactory test than the one-minute double-voltage test usually given would be a considerably higher voltage for a much shorter period. Take, for instance, a 20,000 volt transformer; the insulation of this transformer, if in perfect condition, would probably stand 80,000 volts for several minutes. The testing room high potential test I would suggest in such a transformer would be 50,000 volts for ten seconds.

When the machine is installed and is just going to be put into operation, it is to be tested again to see if it has got damaged during transit. Then I think a much lower voltage test, say a high potential test at 50 per cent., above the operating voltage and an insulation test, would usually be conclusive as to whether or not the insulation was in satisfactory condition.

MR. C. E. SKINNER:—In regard to the duration of test for the determination of whether the contract is fulfilled or not, I think the recommendation of the Standardization Committee is quite fair both to the manufacturer and to the customer. Their recommendation is for a test of double the potential at which the apparatus is to be used, applied for one minute. Longer tests are liable to cause trouble, as stated by Mr. Thomas, and the manufacturer usually makes his own tests higher to determine whether or not he has succeeded in carrying out his designs to his own satisfaction.

Mr. Thomas has perhaps given the impression that a great deal of caution is necessary. Caution is necessary, particularly with very high potential tests, but I feel that such tests should be carried out on all apparatus.

In regard to the method of application of the voltage, I think this might properly come up under Mr. Thomas' paper and very little is said about this matter.

There are three principal methods which are in use: The static voltmeter in the high-tension circuit; the direct reading voltmeter used with a multiplier; and the ratio of transformation measuring the voltage on the low-tension side. The spark-gap is recommended by the INSTITUTE, but I agree with a former speaker that it is an unsatisfactory and dangerous method.

Theoretically the static voltmeter in the high-tension circuit is the best, but it is difficult to obtain an entirely satisfactory static voltmeter. The use of a multiplier in connection with a direct reading voltmeter is open to the objection of large consumption of

power on very high voltages and the difficulty of building and maintaining the necessary series resistance.

With large testing transformers the ratio of conversion is in most cases adequate for the purpose. There may be a slight rise of potential when the static capacity is considerable, but this is not of very great consequence. The amount is not sufficient usually to cause any particular damage, as the apparatus must have a strength considerably above the contract test in order to pass either without giving trouble.

In regard to applying the voltage, it is sufficient on low-tension apparatus, say, tests up to six, eight or ten thousand volts, to simply switch in the potential at which the test is made. There will be a rise of the e.m.f. across the testing terminals, but the factor of safety, if you may call it such, will be sufficient, or should be sufficient to stand this rise; and where hundreds and even thousands of tests are made every day, as they are in the large factories, it becomes quite a serious loss of time, in making the tests, if considerable time is taken to bring up the voltage. For the higher potentials, it is necessary to raise the potential gradually, and there are various schemes for doing this. One of the best is to have control of the generator. That is not always possible. Where we are obliged to make the test from a constant potential system, then it is necessary to introduce something in the nature of water resistance or of a step-by-step method, using very small steps. Where the capacity of the apparatus to be tested is quite small, such as insulators or small sets of cable, steps as large as 5 per cent, do not seem to be objectionable. Where the static capacity of the apparatus under test is large the steps must be smaller to prevent surges in the testing circuit.

MR. MERSHON:—I thoroughly agree with what Mr. Peck and Mr. Skinner have said. I have no love for what might be termed an "egg-shell" transformer. It seems to me that we want something that is going to stand a little rough knocking about. If we have to handle 40,000 and 50,000 volt transformers so gently, what is going to happen when we get up to the voltages that are being talked about, 100,000, perhaps?

As regards the question of injury to the apparatus under test, at, for instance, double potential test for a minute. The problem is simply this, that we want to get apparatus which will meet and withstand the conditions of practical operation. Now, we cannot state accurately and explicitly what those conditions are. Therefore, we cannot formulate explicitly any tests which will show whether or not the apparatus will meet them. The best we can do is to adopt tests which, in the light of experience will probably come somewhere near telling us whether the apparatus is going to meet the practical conditions. It seems to me that a double potential for one minute is not any too high, and I can tell you that it is very comfortable to know, under some conditions that obtain on transmission lines, that your transformers have stood such a test.

In regard to when and where the test shall be made, I want to emphasize what Mr. Peck says. It seems to me that the test should be made after the installation of the apparatus. We want apparatus that is going to stand the conditions to which it is subjected after it is installed.

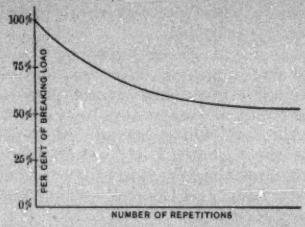
The stand taken by Mr. Peck regarding the improvement in the condition of the apparatus after installation, I agree with entirely. Presumably the manufacturer gets his apparatus in the best possible condition before it is tested. It is not fair that the severity of the test should be reduced in any way because the condition of the apparatus is going to improve with time, when in the meantime the apparatus may be damaged by lightning or other disturbances on the line, and the burden of that loss fall upon the purchaser.

MR. DUNN:—What we need to solve a good many of these questions is data on the relation between the elastic limit of insulating materials and their ultimate break-down point, just as we have that data for mechanical properties of various materials. To refer to the case mentioned by Mr. Lincoln, I think it would be good engineering for Mr. Stott to try to break the suspected base of the generator with a reasonable excess of strain over what it was expected to stand regularly.

Insulation testing is of two kinds. One, as I said before, to determine whether the insulation is present. This is necessary even if a manufacturer is honest, because in putting conductors into slots and wires around cores, considerable mechanical pressure and hammering has to be used, which is liable to break the insulation or subject it to such pressure that its properties are injured. The other kind of testing is to determine whether insulation which we believe present is good. In this test we apply a stress that is above the elastic limit. If we could determine that the elastic limit of the insulation was say one-third of the ultimate limit, it would be proper for us to use a high potential test within the former limit. The stresses we put on apparatus in factory tests now are above that limit, and we keep them on but a short time in order not to damage the insulation too much. Such tests, I think, are bad. If one of the results of this discussion were the collection of data on elastic limits, it would be of great benefit.

PROFESSOR LANGSDORF:—There is another kind of test, which so far as I know has never been applied to insulating material. It is analogous to those which are made upon metal, and recently upon cement, to determine the effect of fatigue. I have recently seen a curve which was made from the results of tests of this nature on cement that looks something like this (indicating); the number of repetitions necessary to produce failure are plotted as abscissæ, and percentages of the normal breaking load as ordinates. The curve is apparently logarithmic and approaches an asymptote passing approximately through the 50 per cent. division on the scale of ordinates; this

would mean that the factor of safety as ordinarily understood is only half the assumed value; so that if tests of this nature could



be made on insulators we might get a little more light upon the value of the factor of safety.

MR. HENRY PIKLER:—When we are testing electrical apparatus we assume a sine wave e.m.f. This is true as long as the step-up transformer is directly connected to the terminals of the generator which furnishes the sine wave high voltage, but as soon as we use resistances in series with the transformer in order to control its terminal voltage the wave-shape of the e.m.f. changes. You know very well that the hysteresis, or more correctly, the change in the permeability during one cycle of magnetism distorts the wave-shape of the magnetizing current; but if we have in the circuit besides the transformer, a series ohmic resistance, then this will cause the distorted current to change again to a sine wave. And when a sine wave current excites the transformer, its induced e.m.f. will be no longer a sine wave but a highly peaked wave, and we subject the tested apparatus to a voltage which is perhaps 20 per cent. higher than we are calculating on. I made some experiments in this regard, and I found that the more the energy consumed by the ohmic resistance comparatively to the energy consumed by hysteresis in the transformer, the less will be the distortion of the current wave, it will become more and more sinusoidal. But if the transformers get a sinusoidal magnetizing current, its induced e.m.f. wave will be distorted, assuming as a limit a perfect sine wave shaped exciting current. The induced e.m.f. wave of the transformer will have exactly the same shape as the exciting current curve has, when the current drawn from the sine wave generator is only that due to the transformer, the secondary of which is open.

It has been suggested that we should know the relations between the ultimate strength and the elastic limit in insulating materials. The insulation engineer has a very difficult problem to handle. With low voltages it is fairly simple; but when we get up to the higher voltages, there arises a new order of affairs. One of the things to guard against particularly is that we do not

encounter unawares a new kind of phenomenon. For example, when we test at two or three times normal voltage, we are simply endeavoring to determine the breaking down strength. Some new phenomenon like dielectric hysteresis may come in to produce heating, or in suddenly applying the voltage for test there may be some sudden rise of voltage which was not anticipated. It is things of this kind, these incidental and unexpected things, which we must guard against particularly.

MR. THOMAS:—I will take only a moment or two The building and testing of high-tension apparatus, transformers or generators, is an extremely intricate and complicated problem, and no person who has not worked on a design and used such material can have any real appreciation of the difficulties involved. These criticisms and recommendations, if we may call them such, which I have drawn up here, are based on a very long line of experience, tests, actual apparatus troubles, and represent a very careful consideration of all the data.

Mr. Peck began by calling attention to the fact that the apparatus is likely to get strains on layers near the terminals of the transformers during the early testing of the line and that tests ought to be made in apparatus purposely to apply these strains. This would certainly be very desirable on the face of it, and is desirable if it can be carried out practically. But this great difficulty is met: Suppose you make the test and our transformer fails to stand it. You can't always know the fact. A spark occurs between two layers inside somewhere, and since the apparatus is, in all probability, not in a position to be supplied with generator current to the full capacity of the system, your insulation is punctured, the spark passes and ceases, stops, and you think the transformer is all right. You go ahead and a little later a strain of much less magnitude comes along and when conditions are favorable for that fault to be developed, and the general apparatus breaks down. That is one of the difficulties.

[CONTRIBUTED AFTER ADJOURNMENT BY DR. LOUIS BELL.]

I do not think it wise for a purchaser of apparatus to place much reliance on over-voltage tests set forth in contracts, save in the case of line insulators, switching and such-like simple apparatus. In other cases such tests ought not to be long continued, and should not be made until the apparatus has successfully stood a full load test and recovered therefrom. Then a moderately severe over-voltage test can be usefully applied, merely to try out the insulation as a whole. I do not concur that a disrupture test is unfair because it may subject to severe strain parts of the insulation which normally receive in commercial working only a moderate strain. The disrupture test ought to try out these very points, for danger to insulation from minor lightning discharges, resonance and the like frequently catches apparatus at just these weak points, since trouble usually comes from abnormal, not ordinary, conditions. Personally, I

attach some value to an overload test at a voltage somewhat greater than will ever be demanded in practice, with careful insulation measurements before and after.

[CONTRIBUTED AFTER ADJOURNMENT BY MR. P. G. GOSSLER.]

The grounded wire method of protection against lightning has been used on the transmission lines of the Montreal Light, Heat & Power Company for the last four years, with very satisfactory results. For three years the transmission lines were operated at two-phase, 12,000 volts and for the last year at 3-phase, 25,000 volts.

The 2-phase transmission lines consisted of duplicate lines run from Chambly to Montreal, the total distance being about 17 miles for each line of which 14½ miles were ærial and 2½ miles single-conductor rubber-insulated underground cables. The underground cable was divided up in three sections, the first section was about a mile and a half from power house, the second about 15 miles from the power house, and the third at the Montreal end.

The present transmission lines consist of duplicate lines, 17 miles for each line of which 15½ miles is ærial, and 1½ miles underground cables at one end. Three lines of barb wire are run on pony glass insulators on each pole line, two lines being run on the ends of the top across-arms 32 inches from the line wire, and the third on a pin on the top of pole.

The barb wire is composed of two twisted No. 12 B.W.G. galvanized iron wires with one four point barb every five inches, and is connected at each pole by means of a soldered joint to the ground wire. This ground wire is stapled down the face of the pole and is twisted several times round the butt, after running through an iron pipe about 8 feet long, which projects above the level of the ground, preventing the wire from being cut or broken, as well as affording an additional ground.

As the poles are set 90 feet apart the barb wire lines are grounded about fifty-eight times per mile: this frequent grounding being one of the most important points in the protection.

It has been the general opinion that ordinary barb wire lacks good mechanical properties, is liable to corrosion and to cause interruption to the service by breaking and becoming tangled with the transmission wires.

This has not been our experience. In the line described above, ordinary commercial barb wire was used and we have only experienced two cases of the barb wire breaking. In both cases it fell clear of transmission wires and did not become entangled with the conductors. We are of the opinion that our freedom from mechanical troubles has been due to the care exercised when stringing the line, and also fastening to a glass insulator, instead of stapling to the cross-arms and top of poles.

We also use the Westinghouse low equivalent a.c. lightning arresters, in conjunction with the barb wire. Banks of arresters being located at both ends of the ærial lines.

We have undoubted proof of the usefulness of barb wire protection as applied to our system. The first year and a half of operating our 12,000 volt Chambly Plant we did not have any protection against lightning but the barb wire. The first summer we had the opportunity of watching the effect of a very severe storm which traveled from Montreal to Chambly, passing over the district through which our transmission lines run; this storm did considerable damage in Montreal, shattered several trees along the transmission line, and also damaged the local lines in Chambly, but no trouble was experienced on the transmission lines.

So satisfied are we of the usefulness of barb wire as a protection that we have installed it on many of our local 2400-volts circuits in and around Montreal, with satisfactory results.

To be presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

CHOICE OF FREQUENCY FOR VERY LONG LINES.

BY P. M. LINCOLN.

Although other frequencies are in use in this country, there are only two which by the extent of their use can be called standard, viz.: 60 and 25 cycles per second. Without discussing the relative merits of other frequencies, the question now presented is, which is the better frequency for a very long line, 60 or 25 cycles per second, considered purely as a transmission problem.

In the present state of the art, 200 miles may be considered as very long for a transmission line. Although longer ones have been proposed, only one of this length has been put into actual operation and no other line approaches this length. The reasoning which follows will, therefore, be made to apply to a typical line 200 miles long.

Frequency has a direct bearing upon voltage regulation and charging current and its influence on a possible condition of resonance may also be profitably discussed.

1st. *Voltage Regulation.*—The difference between the voltage at the transmitting and the receiving stations, termed the "drop," is dependent upon several elements, among which are the resistance and the inductance of the circuit. The volts for overcoming the resistance are the same as would be required for sending a direct current equal to the normal alternating current through the line, if it be short-circuited at the receiving end. The volts for overcoming the inductance at any frequency are measured by the pressure which would be required for sending the alternating current at that frequency through the short circuited line, if the ohmic resistance were negligible. The inductance volts are directly proportional to the frequency. The difference in voltage between the transmitting and receiv-

ing stations, or the "drop," is a function of the resistance volts, the inductance volts and the power factor of the load.

Consideration of voltage regulation at the receiving end limits, according to best practice, the resistance volts in a transmission line to about 15 per cent. as a maximum, and the same consideration should keep the inductance volts within a maximum of 20 per cent. This will mean a line regulation of about 24 per cent. with a load power factor of 85 per cent. Best economy may reduce the resistance element below the maximum given. The resistance volts may be reduced to any given amount by the addition of copper, while inductance volts are little affected by increasing the size of wire. An increase in size of conductor which will reduce resistance volts by one-half will reduce inductance volts only about 5 per cent. The matter of inductance volts, therefore, constitutes a limit to the amount of power that can be delivered over a single line. This consideration will limit the amounts of power which can be delivered by a three-phase line 200 miles long to approximately the following:

TABLE SHOWING LIMITS OF TRANSMISSION LINE CAPACITIES.

Voltage at Receiving End. 200 Mile, 3-Phase Line.	Power Delivered with 20% Inductance Volts.	
	60 Cycles.	25 Cycles.
20,000 Volts	500 k.w.	1,250 k.w.
30,000 "	1,125 "	2,800 "
40,000 "	2,000 "	5,000 "
50,000 "	3,125 "	7,800 "
60,000 "	4,500 "	11,250 "
80,000 "	8,000 "	20,000 "

For longer or shorter lines the k.w. in the above table may be decreased or increased in direct proportion.

If the amount of power to be transmitted is large, the multiplication of lines necessary at 60 cycles unduly increases expense both of pole lines and of right of way for same. This point is evidently in favor of the lower frequency.

2d. *Charging Current.*—Charging current is, of course, a direct function of frequency and voltage and to a slight extent of line construction. At 60 cycles the apparent energy represented by the charging current in a 200-mile three-phase line is practically equal to the ultimate capacity of that line as limited by the 20 per cent. inductance volts consideration. At 25 cycles it is only about 15 per cent. of the ultimate capacity as limited by the same consideration. In a 60-cycle installation,

therefore, it is necessary either to operate the generators on such a line at about full current output all the time, no matter what the load, or to compensate for the charging current in part or in whole by the installation of choke coils, either horn of which dilemma is not pleasant to consider. The problem of taking care of the charging current at 25 cycles does not enter the discussion as compared with 60 cycles.

The effect of a large charging current on the regulation of the generator should also be considered. As is well known, a line charging current, when circulating in a generator armature, has the effect of assisting the field ampere turns to magnetize the fields. The percentage of magnetizing done by this charging current depends upon its amount and the inherent regulation of the generator. Since the charging current depends upon the voltage, the generator exciting power of the charging current also depends upon the voltage. The effect of sudden load changes, therefore, which tend to change the voltage delivered, will in turn affect this element of the excitation. That is, to a certain extent, the generator assumes the regulation which inherently belongs to a d.c. shunt generator. The effect of large charging currents on generator regulation is, therefore, not toward an improvement.

3d. *Resonance.*—As is well known, every combination of a condenser and choke coil in series has a natural period of oscillation, whose value depends upon the square root of the product of the condenser capacity by the choke coil inductance. If a frequency of its natural period be applied to such a combination, resonance will occur. That is, a small exciting force of the proper frequency will cause comparatively large currents to circulate between the condenser and the choke coil and therefore comparatively large voltages across both the condenser and choke coil. This is an example of resonance in its simplest form.

A transmission line possesses both capacity and inductance, and therefore the possibility of becoming resonant under certain conditions. The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed, and omitting the

effects of translating devices. Under this assumption, we may consider that the capacity of a distant portion of the line is in series with the inductance of the intermediate portion.

The natural period, that is, the applied frequency at which resonance will occur between the parts of a transmission line, will be a minimum when the two parts are equal, or each is equal to one-half the total line. The number of natural periods above this minimum is infinite, since it is possible to divide the line into two parts, the inductance of one of which multiplied by the capacity of the other may be any quantity less than that obtained by dividing the line into two equal parts.

The minimum period of a 200-mile line is approximately 200 cycles per second. There is, of course, no danger that the fundamental applied frequency will produce resonance until the length of line largely exceeds 200 miles, but the same cannot be said of some of the harmonics if they are sufficiently prominent. The lower the fundamental frequency, the less is the danger from this source. So far as the writer is aware, no actual trouble has ever been experienced in existing plants from this source even on the longest lines and highest frequencies in use, but it nevertheless constitutes an advantage for 25 over 60 cycles that cannot be dismissed with a scoff.

It is a fact that the longest transmission line in the world—the Bay Counties line in California—as well as the highest voltage line—the Missouri River Power Company in Montana—are both operating at 60 cycles. These facts, however, do not detract from the force of the preceding reasoning.

It is not claimed that this discussion contains all of the arguments pro or con. The bringing out of additional points as well as the soundness of those presented, is left to the discussion which it is hoped the above will provoke.

WEDNESDAY—AFTERNOON SESSION.

President Scott called the meeting to order at 2.30 P. M.

MR. B. A. BEHREND:—Mr. Lincoln's figures indicate clearly that, with a given amount of material in a long line of power can be transmitted at 25 cycles than at 60 cycles. Mr. Lincoln calls attention to the possible danger of resonance as produced by the higher harmonics superimposed upon the fundamental used for the transmission. Mr. Lincoln says: "The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed and omitting the effects of translating devices."

I showed in a brief contribution to M. Leblanc's paper at the Convention of the INSTITUTE last year that the natural period of oscillation of a transmission line with distributed capacity and self-induction can, without difficulty, be calculated. The method in my contribution requires no extraordinary mathematical knowledge beyond simple differential equations, and I have shown on page 1213 of our volume of 1902 that the fundamental of the natural frequency of oscillation of the line is:

$$\frac{1}{4_L\sqrt{LC}}$$

while the natural frequency, if we assume the capacity and self-induction to be concentrated, is equal to,

$$\frac{1}{2\pi\sqrt{L_1 C_1}}$$

The discharge frequency of a long line with distributed capacity and self-induction is, therefore, greater than if the capacity and self-induction were concentrated.

Although this is all very interesting, I feel somewhat skeptical about the practical importance of this resonance. It may be possible that such resonance occurs on long transmission lines, but I should prefer to suspend judgment on this point until the facts had forced themselves upon my attention. I cannot help thinking of the unreasonable importance which at one time used to be attributed to the wave-form of alternating current generators a case which has almost entirely broken down. But, at one time, the wave-form was the scapegoat for all sorts of mistakes made and a perfect bugbear to the designing engineers.

In considering the question whether a frequency of 25 or 60 cycles is preferable for power transmission purposes, we should not confine our attention to the line itself, but we should take

into consideration the generating plant, the transformers and the substation as well. In regard to the generating plant and the transformers, there can be no doubt that a frequency of 25 is rather lower than desirable. In regard to the substation apparatus, a frequency of 25 is as high as desirable for rotary converters, while it is too low for lighting. Is not, after all, then, Mr. Lincoln's problem the same that has been argued for fifteen years, viz., the problem of the most favorable frequency?

I may add to Mr. Lincoln's statement to the effect that the longest lines, as the Bay Counties and the Missouri River, are operated at 60 cycles, that the first long distance transmission line of 115 miles in length between Lauffen and Frankfort, which was built in 1891, was operated at a frequency of 50.

MR. F. G. BAUM:—The first criticism I have to make on this paper is that it confines the discussion of the choice of frequency to the transmission line.

Unquestionably, so far as the line is concerned, the lower the frequency the better the regulation, and the greater the capacity of the line, limiting the capacity of the line by the inductive volts. But the fallacy of reasoning that a low frequency is, therefore, to be used, becomes immediately, evident if we pass to the transformers, where the higher the frequency, the smaller the weight and cost, and the greater the efficiency.

The best frequency for the generators is, of course, dependent upon the speed at which they are driven, and on their capacity. With slow speed engines, low cycles would no doubt be preferable, but in water power plants, operating at speeds from 300 to 500 r.p.m., with peripheral speeds of about 10,000 feet per minute, according to the head of water used, the best frequency for the generators will be higher than when driven by low speed engines.

A power company at the present time, in California at least, if it is to be a success, must sell a good proportion of its load to small towns for lighting, etc. These towns being already equipped with 60 cycle apparatus, practically force the power companies to supply that frequency.

As to the limits of the percentage of resistance pressure or copper loss, I believe 15 per cent. as a maximum is a little high, and a satisfactory system should probably not have over 10 or at most 12 per cent. The limit of 20 per cent. for the reactance pressure is, I think, a little low. As it is possible generally to have pretty fair control of the power-factor of the line, a maximum of 30 per cent. for the reactance pressure would, I think, not be excessive, and would give satisfactory service.

The charging current is not difficult to handle. If the load is to be mostly induction motors, the charging current will improve the power-factor of the generators. However, a 30 cycle system would be better than 60 cycle so far as handling the charging current is concerned.

Undoubtedly if our lines are to increase in length to 300 and

up to 500 miles, we must operate at less than 60 cycles, in order to reduce the reactance volts and also on account of coming into resonance with the line.

PRESIDENT SCOTT:—This paper is another example of what was referred to this morning in another connection; namely, the new class and order of phenomena which may appear when the voltage is changed. The various points which have been taken up in this paper; namely, regulation, charging current and resonance, have little or nothing to do with the choice of frequency at low voltages. For instance, in an installation of an isolated plant, or one for short distances, in which the voltages are not more than a few thousand. But when the higher voltages and the longer distances come in, then these new problems appear; new elements have very great importance, sometimes they are even the limiting conditions. The subject is one which is open now for general discussion.

MR. MAILLOUX:—It seems to me that in a matter of this kind the consulting engineer is confronted more by conditions than by theories. If he has to consider locations where the electrical energy is to be used principally for lighting, he must of necessity adopt a frequency that will be compatible with satisfactory lighting. In all the cases which I have had to deal with in long-distance transmission thus far, that condition has been imposed by the facts and circumstances of the case. It has been necessary to make provision for a current capable of giving satisfactory lighting, because the bulk of the current was intended to be used for that purpose. Now the question it seems to me, therefore, would be, in striving to obtain a compromise between extremes, to determine what is the minimum frequency that is satisfactory for lighting purposes. Experiments have been made with the various frequencies in Europe. There are many plants which are furnishing or attempting to furnish lighting current with frequencies as low as 40. I have seen several of those plants, and I must say that I do not consider them satisfactory. One can see stationary objects very well, but moving objects seem to have a jerky motion which is unpleasant and even annoying. I would like to know if any of the gentlemen present have had experience with frequencies as low as 50. It has occurred to me several times that perhaps a frequency of 50 might be a satisfactory compromise. We all know that 60 is perfectly satisfactory for lighting, but it would be very interesting to know what experience has been had with frequencies lower than 60, in this country.

MR. STOTT:—As to the frequency at which incandescent lighting becomes impossible, I think that point comes at just about 20 cycles, from some experiments which have been carried out. Twenty-five cycles, with a low efficiency lamp, taking about 4 watts per candle, and with a voltage not to exceed 110, where the filament is comparatively heavy, is quite satisfactory. We have tried the experiment of having direct current lighting in

the draughting room and then without notice throwing it over on the alternating current, and no one knew anything about it; and this certainly demands the best light possible.

PRESIDENT SCOTT:—You are using it in the elevated stations in New York?

MR. STOTT:—Yes; we have about 30,000 incandescent lamps run now on 25 cycles, and very few people notice the fluctuation. I think it depends a good deal upon the voltage regulation and also upon the fact that low efficiency lamps are used.

MR. MAILLOUX:—How about the Nernst lamp?

MR. STOTT:—I have no information about the Nernst lamp. I understand 25 cycles is rather low for it. In reference to the general proposition of frequency, it seems to me that it is a local condition which must be considered in connection with every individual proposition which is brought up.

MR. MERSHON:—Mr. Lincoln considers his subject purely as a transmission problem. It is not very often that you get a chance to consider the engineering of transmission from that standpoint. You generally have to take into account certain conditions that have to be met. You cannot select the frequency of your apparatus just as you choose. Now, in many of these cases—I guess it has been true of all the California plants—I think it is true of most all the transmission plants that have been put in—the condition to be met first was that of delivering power at 60 cycles. The transmission enterprises could not have existed, probably, if you had insisted on putting in the 25 cycles, in that there would not have been enough immediate prospective market to have made it possible to finance the enterprise, and in order to get this market, and get it as soon as the plant was in operation, it was necessary to deliver 60 cycles. In such a case, the question comes down to whether or not it is better to transmit at 25 cycles and use frequency changers for 60, or whether it is better to transmit at 60 cycles and use synchronous motors to raise the power-factor of your load, or even bring up the drop in your line to approximately that of the copper drop. If you consider the question of the investment in these cases, you will find that the 60 cycle plant shows up much more favorably. Take, for instance, the use of motor generators for changing your frequency from 25 to 60 cycles—you would require, with a power-factor of 85, which is the one Mr. Lincoln has taken, approximately 220 per cent. in actual machine capacity, counting both motor and generator, and the fact that your generator has got to be able to take care of a power factor of 85. If you are using synchronous motors and bring your power-factor up to unity, it will require about 53 per cent. Now, that represents not only the cost of the machines, cost of the switchboard apparatus for handling them and cost of station room for installation of machines, but in addition to that there is the question that has been mentioned of the less cost of the transformers for 60 cycles. As regards the question of the charging current on 60 cycles, if synchronous motors

were used, you would be able to get a greater amount of power over a single line than Mr. Lincoln has calculated. Besides, you could reduce the effect of the capacity current on the generator by means of these synchronous motors, by keeping some of them running at light loads just as you would have to do in case of frequency changes. I cannot see that the capacity current of the line will seriously affect the generator regulation. The generator excitation depends upon ampere-turns either in the field winding or the armature winding. To the over-excitation, required to neutralize the armature-reaction of a given lagging load, is due, mainly, the rise in voltage when such a load is thrown off. If the same lagging load be carried but in conjunction with a charging current, such as brings the power factor at the generator terminals to unity, the unity condition is due to the fact that the reaction component of the lagging load has been neutralized by the charging current. When, therefore, the lagging load is thrown off, there is left on the generator the charging current whose effect on the generator magnetization is about equal to, in fact somewhat less than, that of the over-excitation previously referred to. True, the rise of voltage tends to increase the charging current which in turn tends to increase somewhat the voltage rise, but this cumulative action will be held in check by the fact, just referred to, that ampere-turns in the armature are less effective in raising voltage than an equivalent number of ampere-turns in the field.

As regards the question of frequency in lighting, I think there is an element to be considered that has not been mentioned, namely, personal peculiarities. I have tried in a number of cases to find out the impression made on different people by low frequency lighting. At 25 cycles, if I endeavor to do so, I can notice a flicker in any 25 cycle installation I have ever seen, but it does not bother me. Some people say that it annoys them at all times, and some people say that they can even see the flicker in the case of frequencies considerably above 25 cycles. I think, however, that the majority of people cannot notice any effect from 30 cycles. Possibly they could with quick movements of illuminated objects, but I do not think that with the ordinary movements of every day life they would notice any flicker at 30 cycles.

MR. RUSHMORE:—An interesting instance came to my notice some time ago in talking with an engineer of one of the large transmission systems. On some of their new lines, he said that they were using a maximum distance between wires for the purpose of obtaining the greatest possible line inductance, the rise in voltage being greater than was desirable.

The form of e.m.f. curve has been mentioned as being something about which we need at present concern ourselves but little. This is quite opposed to my own view. The capacity charging currents on these high voltage lines very considerably amplify any harmonics which may exist in the original wave.

Under such conditions, it is necessary that the wave-form approximate closely that of a sine function. In modern generators this is the case, which perhaps explains to some extent the reason why but little is heard on the subject.

MR. LINCOLN:—Mr. Mershon advanced the idea that synchronous apparatus could be operated at the receiving end of the line to compensate for the inductive drop. I wish to take issue on that point. It is possible so to operate synchronous apparatus that the current at the receiving end of a transmission is either lagging or leading with respect to the e.m.f. at the will of the operator. That is, the inductive "drop" in the transmission may be made to subtract from or add to the generator volts at the will of the operator. This fact, however, is not going to help line regulation, that is the change in receiving end voltage for a given load change—unless the field strength of the synchronous apparatus can be changed automatically with load. The limiting factor in very long lines is regulation and I do not see how Mr. Mershon's scheme of putting synchronous apparatus at the end of the line helps regulation. And for the same reason I would differ from Mr. Baum where he places the real loss in a transmission line at somewhat less than I have. I have placed it at 15 per cent. He says it is not over 10 per cent. or 12 per cent., and he places the inductance drop at 30 per cent., instead of 20 per cent., as I had it. That inductance drop is going to have an important influence in the regulation of the line, and if we are going to limit our regulation to 25 per cent., I don't see how you are going to allow 30 per cent. inductance drop, particularly with loads of low power-factor.

MR. MERSHON:—I cannot quite agree with Mr. Lincoln. The action of a synchronous motor with a constant excitation is similar to that of a condenser so long as the voltage impressed upon the motor does not vary, but as soon as the voltage begins to vary the similarity ceases. If the voltage rises on a condenser the condenser takes more current. If the voltage rises on an over-excited synchronous motor the motor takes less current. The voltage may rise to a point where the motor will take practically no current or it may increase to a point enough greater than this so that the motor instead of taking from the line a leading current, it will take a lagging current tending to pull down the voltage, or rather, limit the rise. The action of the idle synchronous motor is therefore corrective which a condenser would not be. This corrective action of a synchronous motor will depend for its amount on the inherent regulation of the motor. If we chose to go to extremes we might make the synchronous motors dominate the system completely as regards the delivered voltage and might keep the voltage variation as low as we pleased by employing motors with very low inherent regulation.

DR. PERRINE:—I would like to say that whether it is possible or not to regulate a line with a synchronous motor as the last speaker describes, it has never been done; but

the regulation of the line by means of an automatically excited synchronous motor has been done and was described by Mr. Baum in his paper presented before the meeting last year, where he showed how he regulated by means of an automatic exciter the voltage of the Bay Counties line at Oakland, overcoming the effect of capacity and inductance on the line by means of synchronous motors.

MR. H. A. STORRS:—If the discussion need not be limited to 200 mile lines, there are one or two points which might be of interest. First, as regards the highest frequency which will produce a noticeable flicker in the lamp. A number of years ago in the laboratory at Columbia College we had a small rotary converter which was under control so that we could produce alternating currents of any frequency we desired, and we made a good many tests with 15 or 20 students at a time, in order to determine what frequency could be detected. The condition is quite different from what it is to go where a system is being operated at 25. You know the frequency, and you look at a lamp, and you say, yes; you can see the flicker of the light. But if you start with a high frequency and gradually lower it, telling everybody to keep his eye on the lamp, different men will at different instants say that they detect a flicker; and if, as you repeat that experiment, the same man detects a flicker repeatedly at the same frequency, why that is pretty good proof that he does detect the flicker. Under other conditions there is a good deal of imagination about whether you detect the flicker or not. As a result of a good many experiments of that kind, with lamps of various efficiencies, we found that 20 or 21 was about as high a frequency as any man could detect repeatedly. In fact, the majority could not detect a frequency of 20.

PRESIDENT SCOTT:—I would like to call attention to one thing. We are here dealing with certain engineering problems. We have a paper here which deals with the engineering question. What are the factors in connection with a line, a very long line, which bear on the determination of frequency; and we have gotten off from that into a whole lot of commercial things which have nothing to do with this question. What have incandescent and arc lamps to do with this? Mr. Lincoln has shown us here that certain facts prevail if we want to transmit at 50,000 volts, 200 miles. If we get beyond 3,000 kilowatts, we are going to exceed certain engineering limits which he has assigned, and he has done well to call our attention to those things, and bring them in as an engineering problem. The specific application will come in somewhere else.

MR. MERSHON:—Mr. President, will you allow me to take issue with you in six words?

PRESIDENT SCOTT:—In a moment. I call attention to this at this time, so that in this discussion we may endeavor to keep in on the plane of engineering rather than commercialism; not that the commercial is not important, but that the other is the important thing here. Now, in six words, Mr. Mershon.

MR. MERSHON:—It seems to me that if you confined this question of frequency to the transmission line alone, there would not be any discussion. We would agree on the 25 cycles or perhaps on direct current. It seems to me that an engineering problem is always more or less commercial. A physical problem is not an engineering problem until it is commercial; it is simply scientific.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1st, 1903.

Y OR Δ CONNECTION OF TRANSFORMERS.

BY F. O. BLACKWELL.

The two alternative methods, Y or Δ, of connecting transformers to a three-phase system, come up for discussion with every three-phase installation. A general statement of the advantages and disadvantages of both connections, as they appear to the writer, is given here with the hope that those engineers who have had most experience with power transmission will contribute their views on the subject.

TRANSFORMERS.

Assuming that three transformers are to be used for a three-phase power transmission and that the potential of the line is settled, each of the transformers, if connected in Y, must be wound for $\frac{1}{\sqrt{3}}$ or about 58 per cent. of the line potential, and for the full line current. If connected in Δ, each transformer must be wound for the line potential and for 58 per cent. of the line current. The number of turns in the transformer winding for Y connection is, therefore, but 58 per cent. of that required for Δ connection and the cross section of the conductors must be correspondingly greater. The greater number of turns in the winding, together with the insulation between turns necessitates a larger and more expensive coil for Δ connection. The larger coil calls for a longer magnetic circuit and consequently a larger and heavier transformer throughout. This is of no importance when the potential of the coil is low or when the transformer is large and the current high. In fact, in transformers in which the current is heavy it is usual to divide the conductors into several multiple circuits for ease of handling and

to avoid eddy current losses that occur when the cross section of the conductor is too large. A few turns more or less in the winding under such conditions is, therefore, immaterial.

In transformers of small capacity wound for high potential, the cost and weight are both considerably in favor of the Y connection of the high potential coils.

Where it is desired to secure the smallest transformers that can be wound for any given potential, the minimum size of wire that can be employed in the windings of the high potential coils and give sufficient mechanical strength, is the limiting feature. A transformer practicable for Y connection may be smaller therefore than can be commercially considered for Δ connection.

The Y connection requires the use of three transformers, and if anything goes wrong with one of them the whole bank is disabled. With the Δ connection, one of the transformers can

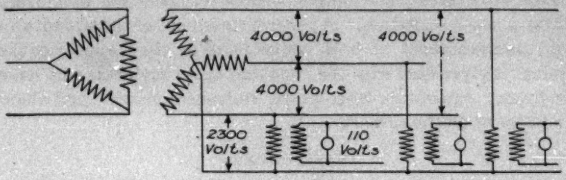


Fig. 1 Step Down Transformer For 4000 Volt Y Distribution

be cut out and the other two still deliver three-phase power up to their full capacity; that is, two-thirds of the entire bank.

Combined three-phase transformers are generally of small size and on that account are preferably Y-connected on the high potential side.

Grounding the Neutral.

If the common connection of transformers joined in Y is grounded, the potential between windings and the core is limited to 58 per cent. of that of the line, and the insulation between the windings and core might be proportionally reduced. The same argument applies to the transmission circuit and would allow the size of the line insulators to be reduced.

The saving that can be made in insulating transformers by grounding the neutral is not great with large transformers, but is important on small ones, as the space taken up by the insulation for any given potential is relatively greater in a small

transformer. Under normal conditions, the potential between any conductor of a three-phase transmission circuit and the ground is 58 per cent. of the line potential, with either Y or Δ connection, but the neutral may drift so as to increase the potential with an ungrounded system. If one branch is partly or completely grounded, the potential between the other two branches and the ground is, of course, increased and may be the full line potential. With a grounded neutral Y system, a ground is a short circuit of the transformers on the grounded branch and the transmission becomes inoperative.

From the point of view of safety to life and prevention of fires this is a desirable condition, especially if the low tension distribution is also grounded. If the high tension circuit makes contact with the ground or low potential system, it can be immediately cut out by fuses or automatic circuit breakers.

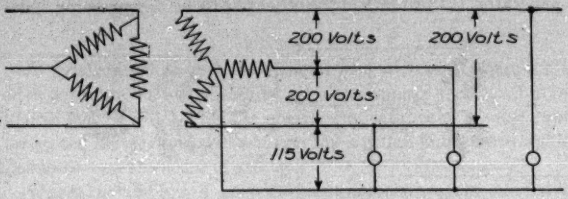


Fig. 2 Step Down Transformer For 200 Volt Y Distribution

The difficulty is that a power transmission with grounded neutral is likely to be frequently shut down by temporary grounds, such as would be caused by a tree blowing against one of the wires. Even if the circuit is not opened, the drop in the pressure due to the sudden "short" on the line will cause synchronous apparatus to fall out of step. Under the same conditions a system without a grounded neutral would give uninterrupted service.

Unstable Neutral.

If two transformers are connected in series, there is no certainty that they will divide the potential equally between them. A system in which all the electrical apparatus is connected in Y has somewhat the same characteristics. The neutral may drift out of its proper place and there will be unequal potentials between it and the three conductors of the circuit, due to unequal loading and differences in the transformers or transmission circuits. Such

unbalancing would cause unequal heating of the transformers and if a four-wire three-phase system of distribution were employed, would seriously interfere with the regulation of the voltage. If transformers, therefore, have Y secondaries, it is desirable that the primary should be Δ connected. Two systems in common use with which Δ primary windings should be used, are shown in Figs. 1 and 2.

Rise of Potential.

The high potential windings of transformers are necessarily of high reactance, and if left in series with a circuit of large capacity, as shown in Figs. 3, 4, 5 and 6, the leading charging current flowing over the reactance may set up extraordinarily high pressures. Figs. 3 and 4 represent Y connected banks of three transformers, each connected so as to cause such a rise of potential. In Fig. 3 the primary of one transformer is excited by a generator, the primary of the other two transformers being open-

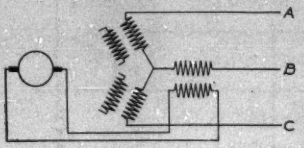


Fig. 3

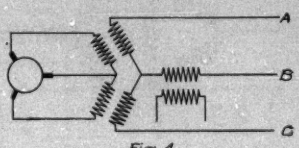


Fig. 4

circuited. In Fig. 4 the primary of one transformer is open circuited, the other two being connected to the generator. Figs. 5 and 6 show T connected banks of two transformers, which might be used to transform from either two-phase or three-phase to three-phase or vice versa, and are similar in action to Fig. 3. If in any one of Figs. 3, 4, 5 or 6 the secondaries are connected to a long distance transmission circuit, a pressure of many times the normal potential will be set up between A and B, and between B and C, that between A and C not being affected.

It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches of one or more of the transformers of a bank connected in Y before the secondary switches are used. Of course, actually, the current jumps across the insulation at some point in the system before there can be any such increase in pressure. If there are a number of banks of transformers in parallel, this phenomena cannot occur except when all but one

bank are disconnected. This source of trouble could be obviated by employing oil switches on the high potential side which disconnect the line before the low tension switches are used, or by triple pole switches on the primary which open all three branches of the bank of transformers at once.

The selection of Y or Δ connection of transformers for long distance transmissions should only be determined after a careful consideration of the conditions in each case.

There is little choice between Y or Δ without a grounded neutral.

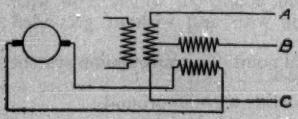


Fig. 5

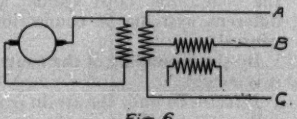


Fig. 6

In small installations, the cheaper cost of transformers for Y with a grounded neutral will be a determining factor. Larger plants will be guided by the greater importance of giving uninterrupted service and will not employ a grounded neutral unless demanded on the score of safety.

Where the amount of power is great and the system extensive, Δ connection will be generally preferred on account of its avoiding the possibility of rises of potential from any cause. Many plants can have advantageously a mixed system with both Y and Δ transformers, each installation of transformers being considered by itself.

[CONTRIBUTION TO DISCUSSION ON F. O. BLACKWELL'S PAPER BY J. S. PECK.]

MR. J. S. PECK:—In his paper, "Star or Delta Connection of Transformers", Mr. Blackwell refers to the grounding of the neutral points of a transmission system, for the purpose of limiting the strain between line wires and ground, and mention is made of the fact that the neutral point is likely to drift out of position and cause unequal voltage strains upon different parts of the circuit.

The question of grounding or not grounding the neutral and of the best method of connecting transformers is one of great importance, and it is the object of this paper to point out some of the conditions, both normal and abnormal, which arise with different systems of connections with and without grounded neutral.

By the grounding of the neutral point of a transmission system it is sought:

First:—To limit the strain from line wires to ground.

Secondly:—To limit the strain between high-tension and low-tension windings of the transformers, also between high-tension windings and iron core.

There are a number of different ways of connecting transformers for transmission work:

Single-phase, 2-phase, 3-phase-delta, 3-phase-T, 3-phase-V, 2-phase-3-phase, 3-phase-star, 3-phase-star-and-delta.

Consider first the case of a single-phase transformer ungrounded, with high-tension and low-tension voltages taken for convenience as 10000 and 1000 respectively, (see Fig. 1) There is evidently a maximum strain of 10000 volts from one high-tension line wire to the other. If the circuits are insulated and symmetrical there will be a strain of 5000 volts from each line wire to ground, and from each extremity of the high-tension winding to the low-tension winding and to the iron core.

If, however, the circuits are not symmetrical, the full strain will not be equally divided, and if in an extreme case one high-tension wire is grounded there will be a strain of 10000 volts from the other line wire to ground; similarly, if one extremity of the high-tension winding be connected to the low-tension winding or to the core, there will be a strain of 10000 volts from the other extremity of the high-tension winding to the low-tension winding or to the core.

The actual strain between adjacent high-tension and low-tension windings is equal to the high-tension voltage plus or minus the low-tension voltage, depending upon the arrangement and connection of the coils; but as the low-tension voltage is usually a small percentage of that of the high-tension, it is customary to assume that the strain between windings is equal to that of the high-tension voltage alone.

If the middle or neutral points of high-tension and low-tension windings are grounded, the iron core being also grounded (see

Fig. 2), then as long as the circuits are in balance the voltage strains will be the same as with the windings ungrounded and balanced; but in case of a ground on either high-tension or low-

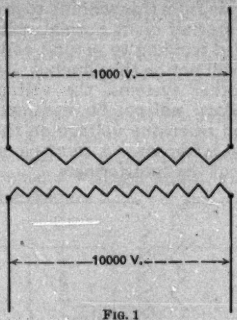


FIG. 1
Single Phase
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

tension line, or in case of a connection between high-tension and low-tension windings, a portion of the windings will be short-circuited. This will, in general, blow fuses or circuit-breakers, thus cutting the transformer out of service; or the voltage of the

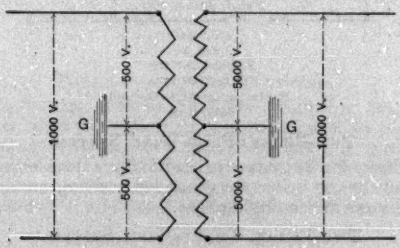


FIG. 2
Single Phase Grounded Neutrals
1000 to 10000 volts
Maximum Strain to Ground
5000 volts

system will be lowered to such an extent as to call attention to the trouble.

Thus, on a single-phase transmission system, the grounding of

the neutral point of primary and secondary windings will limit the strain from line to ground, and from either extremity of high-tension to low-tension and iron to approximately one-half the normal voltage of the system. If the neutral of only one winding is grounded, the strain from this winding to ground will be limited to approximately one-half of its normal voltage, but the strain from the ungrounded winding to ground and to iron and to the grounded winding will not be thus limited.

In considering other systems, the voltage strains between primary and secondary will not be mentioned, as these strains are easily calculated when the voltage on the transformers and the strain to ground is known. A short-circuit on a system will be assumed to cut out the transformers.

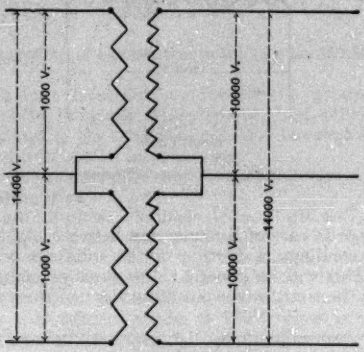


FIG. 3
2-Phase - 3-Wire
1000 to 10000 volts
Maximum Strain to Ground
14000 volts

TWO-PHASE, FOUR-WIRE SYSTEM.

The 2-phase, 4-wire system is practically a double single-phase system, and the conditions for grounded and ungrounded neutral will be the same as for single-phase.

TWO-PHASE, THREE-WIRE SYSTEM.

The voltage across the two outside wires is 1.4 that between the middle and either outside wire. The connections and voltages are shown in Fig. 3, which assumes 1000 to 10000 volt transformers.

A ground on the middle wire will give a strain of 10000 volts between each outside wire and ground, while a ground upon an outside wire will give a strain of 10000 volts from middle wire to ground, and of 14000 volts from the other outside wire to ground.

The neutral point for this system may be obtained from the middle point of an auto-transformer connected across the transformer windings. In this case, a ground upon any line wire will cause a short-circuit on the transformers, thus limiting the strain to ground to approximately .7 normal line voltage.

Thus, with a 2-phase-4-wire or a 2-phase-3-wire-system, grounding the neutral limits the strain from line wires to ground, in the first case to one-half normal voltage, in the second case to .7 normal voltage.

In general, the method of obtaining the neutral point by means of auto-transformers is not feasible on high-tension systems on account of the comparatively great cost of an auto-transformer wound for the high-tension voltage, and it will not be further considered in this discussion.

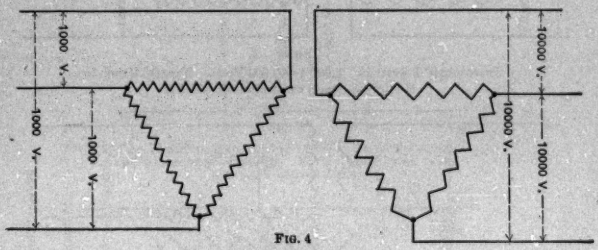


FIG. 4

3-Phase Delta Connection
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

THREE-PHASE, DELTA SYSTEM.

With this system shown in Fig. 4, the strain from any line wire to ground is, with the system in perfect balance, 58 per cent. of the line voltage. In case of a ground on any line wire, the two remaining wires are raised to full line potential above the ground.

With this connection one transformer may be cut out, leaving two connected in V, and the above conditions will not be changed.

THREE-PHASE "V" SYSTEM.

With transformers connected in V, the strains will be the same as when connected in delta.

THREE-PHASE, "T" AND TWO-PHASE, THREE-PHASE SYSTEM.

With either the T or 2-phase-3-phase connection the voltage strains with ungrounded neutral are the same as for the delta system. The neutral point may, however, be obtained from the teaser winding (see Figs. 5 and 6), in which case a ground upon any line wire will short-circuit portions of the windings.

With the 3-phase-T and 2-phase-3-phase connection the grounding of the neutral limits the voltage between line and ground to 58 per cent. of normal.

STAR SYSTEM.

With transformers connected in star the conditions are very similar to those where two transformers are connected with primary windings in series and also the secondaries in series.

Fig. 7 shows such a series combination, neutral not grounded.

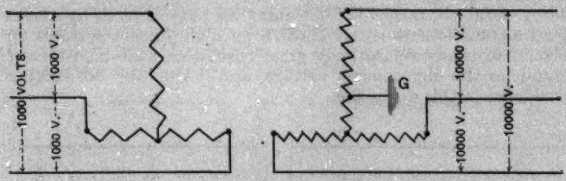


FIG. 5

Three-phase T System. 1,000 to 10,000 Volts. Neutral Grounded. Maximum Strain to Ground 5800 Volts.

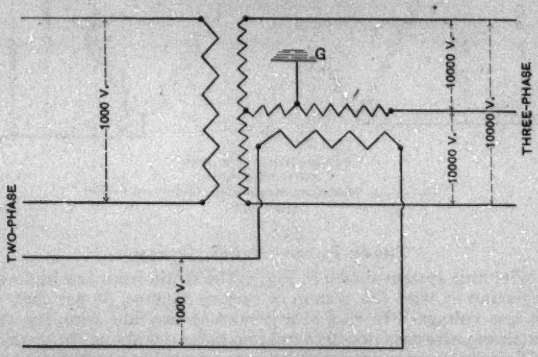


FIG. 6

Two-Phase—Three-Phase System. 1000 to 10000 Volts. Neutral Gronnded. Maximum Strain to Ground 5800 Volts (approx.)

The total line voltage will divide with approximate equality between the two transformers. Between line wires and ground there will exist the same strain as with a single transformer, having the same total voltage; but if one transformer be short-circuited, the full voltage will be concentrated upon the other transformer so that the internal voltage strains on this transformer will be doubled and its iron loss greatly increased, though the strain from line wires to ground may be the same as before.

If the series connection between the two transformers be grounded (Fig. 8), and a ground occur on either line wire, the transformer connected to this wire will be short-circuited and the

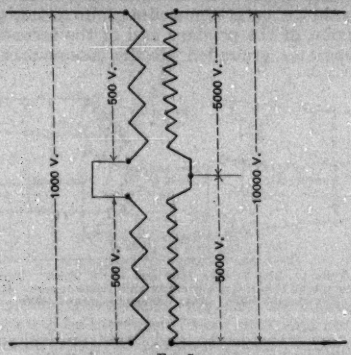


FIG. 7

Two Transformers—1000 to 10000 Volts. Primaries and Secondaries in Series. Each Transformer takes approx. ½ Line Voltage.

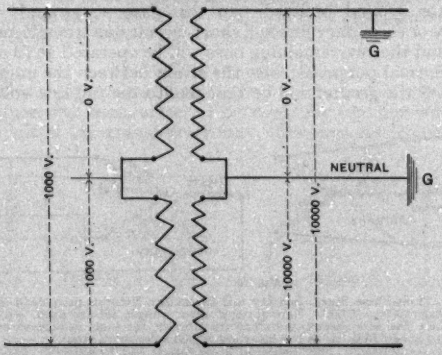


FIG. 8

Two Transformers, Primaries and Secondaries in Series, Neutral Grounded. Ground on Outside Line Wire Short Circuits Adjacent Transformer and Gives Double Voltage on Other Transformer. Full Voltage Strain to Ground.

other transformer will take the full voltage of the circuit and the ungrounded wire will be raised to full line voltage above ground.

Unless the leakage current of the transformer working at

double voltage is sufficient to open the circuit, the transformer may continue to operate indefinitely under the above conditions provided it does not break down, due to excessive heating or to the double voltage strains to which it is subjected.

In Fig. 9 is shown a star-connected group of transformers with the neutral point of the primary and of the secondary, and also that of the generator, grounded. In this case no excessive voltage

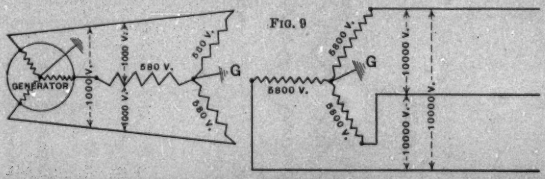


FIG. 9

Three-Phase Star System. Line Voltage 1000 and 10000 Volts. Transformer Voltage 580 and 5800. Grounds on Neutrals of Generator and Transformers. Max. Voltages per Transformer 5800, Max. Voltage to Ground 5800.

can occur on any transformer, and the strain from any line wire to ground is limited to 58 per cent. of full line voltage, for a ground on any line or a short circuit in any transformer will short-circuit the generator.

Fig. 10 shows the same system of connections but with the generator ground omitted. In this case a ground upon a primary or secondary line will short-circuit one transformer of the group and the two remaining ones will be operated at 73 per cent. above normal potential; also the strain between the ungrounded wires and the ground will be that due to the full line voltage.

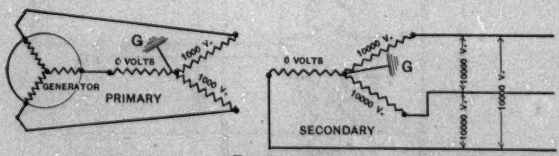


FIG. 10

Three-Phase Star. Primary and Secondary Neutrals grounded. Line Voltage 1000 to 10,000. Normal transformer voltages, 580 and 5800. Ground on one line wire short circuits one transformer, increases voltage on other transformers 73%, raises two line wires 10,000 volts above ground.

Thus for a star connected system the grounding of the neutral points is of no value in limiting the voltage strains on the system unless the neutral point of the generator be also grounded; in fact, the grounding of the transformers without the grounding of the generator increases the chance for trouble, since a ground upon any line wire increases by 73 per cent. the voltage of two of the transformers.

Star-to-Delta System.

Fig. 11 shows a star-to-delta system. With this method of connection no excess voltage can be obtained on any transformer, and not more than full voltage strain to ground, provided the delta remains closed; but with the delta open at one point and a

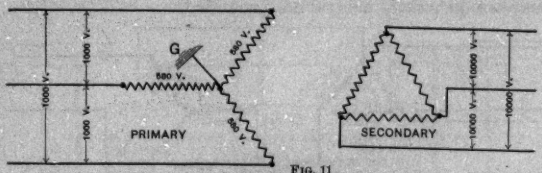


Fig. 11

Star to Delta System.
Line Voltages 1000 and 10000.
Transformer Voltages, 580 and 10000.

short-circuit on one transformer (Fig. 12), the voltage on the two remaining ones will be increased 73 per cent. and across two sides of the delta there will be *three times normal voltage*. Thus, on a 10000 volt circuit, 30000 volts may be obtained in case a transformer is short circuited and cut out of the delta.

This excess voltage across the two sides of the delta is due to the fact that a short-circuit on the star changes the angular position of the voltages from 120° to 60°, which in turn changes the angular position in the delta from 60° to 120°.

Delta-to-Star System.

With this system it is impossible to obtain voltages higher than normal upon any transformer or between any two line wires. A short-circuit in one transformer may, however, cut it out of the

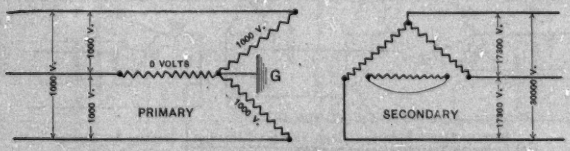


Fig. 12

Same as Fig. 13 except that Delta is opened and one transformer short circuited. Voltage of two transformers increased 73%. Voltage between two line wires increased 200%.

delta but leave the star-connection intact. In such a case the voltages will be as shown in Fig. 13. Two of the transformers operate at normal potential, with normal potential between two of the line wires, but with 58 per cent. of normal between the other wires.

STAR TO DELTA, RAISING. DELTA TO STAR, LOWERING.

In Fig. 14 is shown a transmission system with raising-transformers connected star-to-delta, and lowering-transformers connected delta-to-star. The voltages obtained across transformers and across line wires are shown. The neutral points of the low-tension windings of both raising and lowering-transformers are grounded, generator neutral not grounded.

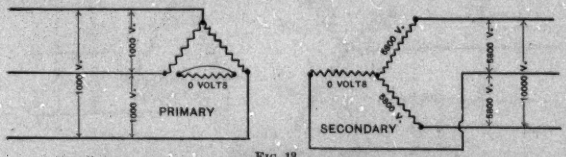


FIG. 13

Three-Phase Delta to Star System. Line voltages 1000 and 10000. Transformer voltage 1000 and 5800. One transformer short circuited and cut out of Delta. Two transformers continue to operate at normal voltage, giving 10000 volts across two line wires, 5800 volts across others.

Fig. 15 shows the voltages which will be obtained with a ground on one low-tension lead which short-circuits one transformer. The high-tension side of this transformer is cut out of the delta. The voltage across the other transformer is increased 73 per cent. and the phase relation changed from 120° to 60°, the voltages being as shown in Fig. 12. On the lowering-delta, three times normal voltage is impressed on one transformer and 73 per cent. above normal voltage on the other two. The voltages obtainable across the star on the lowering-transformers are readily understood from the figure. It will be noted that across one phase there is normal voltage and across the other two phases

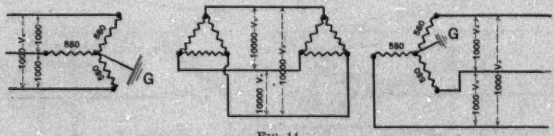


FIG. 14

Star to Delta Raising. Delta to Star Lowering. Neutral of Raising and Lowering Transformers grounded.
Line Voltages 1000 to 10000 to 1000. Transformer Voltage 580 to 1000 to 580

2.7 times normal voltage. It is probable that a transformer subjected to three times normal voltage would take so large a leakage current as to blow fuses.

With this system of connection, grounding the neutral point of the star without a ground upon the neutral point of the generator is of no use in preventing unequal and excessive strains on the transformers and from line wires to ground. Should the

delta on the raising-transformers be kept closed, it is obvious that a short-circuit on any raising-transformer would short circuit the generator, but the above condition is one which might very possibly occur where switches or fuses are placed inside the delta.

DELTA TO STAR, RAISING. STAR TO DELTA, LOWERING.

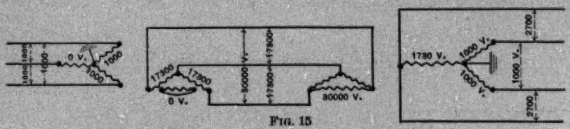


FIG. 15

Same as Fig. 16, except that one raising transformer is short-circuited and cut out of Delta.
Voltages on raising transformer 73% above normal and zero.
Voltages on lowering transformer 73% above normal and 200% above normal.
Voltages on high tension line 73% above normal and 200% above normal.
Voltages on secondary of lowering transformer normal and 170% above normal.

Fig. 16 shows voltages obtained under normal conditions with transformers connected delta-to-star and star-to-delta with low-tension and high-tension voltages of 1000 and 10000 respectively.

Fig. 17 shows approximately the voltages and phase angles obtained when one raising-transformer is short circuited and cut out of the delta, but with the star connection intact. The voltages obtained on the lowering-delta will be approximately those shown. It will be noted that this delta has been twisted far out of its normal form, though the voltage on no transformer has been raised above normal and on the lowering-transformer all voltages are below normal.

Fig. 18 shows the same connection but with one lowering-transformer short-circuited and cut out of the delta. The voltage across one of the remaining transformers is increased 73 per cent., while that across the other remains normal. The voltage across the open side of the secondary delta is increased 165 per cent. above

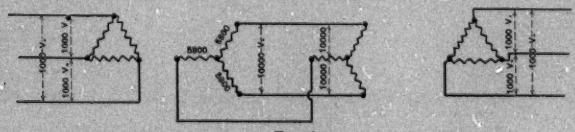


FIG. 16

Delta-to-Star Raising. Star-to-Delta, Lowering. Neutrals not grounded.
Line voltages 1000 to 10000 and 1000; transformer voltages 1000 and 5800 to 1000.

normal; that on one transformer 73 per cent. above normal and on the other it is normal.

If the neutral points of raising and lowering transformers are grounded the abnormal conditions shown in Figs. 17 and 18 cannot be obtained, for in this case, with the lowering-delta closed

as in Fig. 17, the fuses will be blown when a lowering-transformer is short circuited; and with the delta open as shown in Fig. 18, a short-circuit in the lowering-transformer will short circuit the generator.

Some abnormal conditions which may be obtained from a few of the possible combinations of transformers have been given

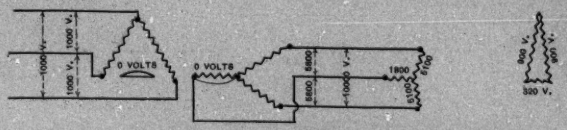


FIG. 17

Same as Fig. 18, except that raising Delta is open and one transformer short circuited. Voltage on lowering transformers less than normal. Note the extent to which the Delta is distorted. If neutral points of raising and lowering transformers be grounded, this distortion cannot occur, as fuses will blow when raising transformer is short circuited.

above. These abnormal conditions are produced by combinations which are accidental or unusual; but it is the accidental or unusual condition which must be taken into consideration and guarded against, if trouble is to be avoided. Some of the conditions which are shown, undoubtedly have occurred in practice and are possibly responsible for some of the troubles on high-voltage transmission systems.

It is obvious that a large number of combinations of raising and lowering-transformers in addition to those given above may be obtained, and in the following tables it has been endeavored to give the most common of these combinations and to show the abnormal conditions which are obtainable.

Resonance.—The abnormal voltages given above are those which are obtained from the generator pressure through direct

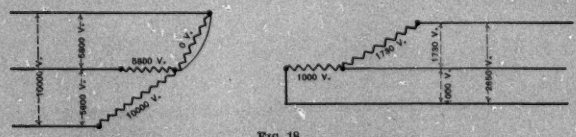


FIG. 18

Same as Fig. 19, except that lowering Delta is open and one transformer short circuited.
Voltages on raising transformers normal and 0.
Voltages on lowering transformers normal, 73% above normal and 0.
Voltages across secondaries normal, 73% above normal and 165% above normal.

transformation. Mr. Blackwell, in his paper, "Star or Delta Connection of Transformers," has called attention to another cause which may produce abnormal voltages, *i.e.*, Resonance. This is particularly liable to occur when a high inductance, such as the winding of an idle transformer is in series with a large capacity, such as that of a transmission line.

In the tables below, where the combination is such as to give an idle transformer in series with an active transformer and a transmission circuit, it is indicated in the column headed " Resonance."

TABLE I.

SYSTEMS OF CONNECTING TRANSFORMERS WITH VOLTAGE STRAINS OBTAINABLE.

SINGLE TRANSFORMATION.

System.	Neutral.	Maximum Voltage.			Possibility of Resonance.
		Per Trans. %	Between Wires. %	To Ground %	
Single-phase or 2-phase-4-wire	(*a*) Grounded.	100	100	50	No.
Single phase or 2-phase-4-wire	(*b*) No Ground.	100	100	100	No.
2-phase-3-wire	" "	100	140	140	Yes.
3-phase Delta	" "	100	100	100	No.
3-phase V	" "	100	100	100	Yes.
2-phase-3-phase or 3-phase T	(*a*) Grounded.	100	100	58	"
2-phase-3-phase or 3-phase T	(*b*) No Ground.	100	100	100	"
3-phase-Star	Grd. or not Grd.	173	100	100	"
3-phase-Star	Transformer and Generator Grd.	100	100	58	"
3-phase-Star to Delta	(*a*) Trans. and Gen. Grd. Delta Open or Close	100	100	100	No.
	(*b*) Grounded Delta Open.	173	300	300	Yes.
	" Closed.	100	100	100	No.
Delta to Star	(*a*) Grd. Delta Open.	100	100	100	"
"	(*b*) Grd. Delta Closed.	100	100	100	"

TABLE II.

SYSTEMS OF CONNECTING TRANSFORMERS WITH VOLTAGE STRAINS OBTAINABLE.

DOUBLE TRANSFORMATION.

System. Raising.	System. Lowering.	Neutral.	Maximum Voltage. Per Transformer. Raising.	Per Transformer. Lowering	Between Wires. High Tension.	Between Wires. Low Tension.	To Grd.	Possibility of Resonance.
			%	%	%	%	%	
Δ Δ	Δ Δ	No Grd., Deltas open or closed	100	100	100	100	100	No.
Δ Δ	Δ Y	" " " " "	100	100	100	100	100	No.
"	Y Y	Grd. or no grd. Deltas, open or closed	100	173	100	100	100	"
"	Y Δ	(*a*) " " " " "	100	100	100	100	58	"
"	"	(*b*) " " " open.	100	173	100	300	100	"
Y Y	Y Y	(*a*) Grd. on all transformers and generator.	100	100	100	100	58	Yes.
"	"	(*b*) No. grd. on generator, transformer grd. or not	173	173	100	100	100	"
"	Δ Δ	(*a*) Grd. on generator and transformer Deltas open or closed	100	100	100	100	58	"
"	"	(*b*) No. grd. on generator, Deltas open or closed	173	173	100	100	100	"
"	Δ Y	(*a*) Grd. on generator and transformers, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, delta open or closed. Trans. grd	173	100	100	100	100	"
"	Y Δ	(*a*) Grd. on generator and transformer, delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, grd. on raising. Delta open	173	173	100	300	100	"

TABLE II.—Continued.

System. Raising.	System. Lowering.	Neutral.	Maximum Voltage. Per Transformer. Raising.	Per Transformer. Lowering	Between Wires. High Tension.	Between Wires. Low Tension.	To Grd.	Possibility of Resonance.
			%	%	%	%	%	
Δ Y	Δ Δ	(*a*) Gr. deltas open or closed	100	100	100	100	58	Yes.
"	"	(*b*) No grd. Deltas open or closed	100	100	100	100	100	"
"	Y Y	(*a*) Grd. on all transformers. Delta closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on all transformers. Delta open	100	100	100	100	100	Yes.
"	"	(*c*) No. grd. Delta open	100	173	100	173	100	"
"	Δ Y	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on transformers. Deltas open	100	100	100	100	100	Yes.
"	Y Δ	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	Y Δ	(*a*) Grd. on transformers. Deltas closed.	100	100	100	100	58	No.
"	"	(*b*) No grd. on lowering on no grd. on raising, lowering delta open	100	173	100	300	100	Yes.
"	"	(*c*) Grd. on raising and lowering, lowering delta open or closed	100	100	100	100	58	"

TABLE II.—Continued.

Y Δ	Δ Δ	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	100	No.
"	"	(*b*) No grd. on generator, raising Delta open, lowering delta open orclosed	173	300	300	300	300	"
"	Y Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No. grd on generator, grd. on transformers, Delta closed	100	173	100	100	100	"
"	"	(*c*) No grd. on generator, grd. on transformer, Delta open	173	173	300	300	173	"
"	Δ Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	100	"
Y Δ	Δ Y	(*b*) No grd. on generator, transformer grd. or not Deltas closed	100	100	100	100	100	No.
"	"	(*c*) No grd. on generator, transformer grd. or not, raising Delta open	173	300	300	270	300	"
"	Y Δ	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, lowering Delta open; grd. on transformers	100	173	100	300	100	"
"	"	(*c*) No grd. on generator, raising and lowering Deltas open; grd. on transformers	173	173	300	265	300	"

In the above tables, it has not been attempted to show all the operating conditions with each of the combinations. The remaining ones may, however, be readily worked out.

In addition to the combinations given above there are the 2-phase-3-phase, 3-phase-V and 3-phase-T connections which may be used at either the raising or the lowering ends. When used for raising-transformers, these combinations will deliver their proper voltages to the line provided the proper voltages are impressed on their primary terminals, as it is impossible by short-circuiting one transformer to raise the voltage of the other.

When used as lowering-transformers these combinations will supply to the secondary circuits, voltages of proper amount and bearing the proper phase relation to each other, provided the voltages impressed on the primary side are of proper amount and proper phase relation to each other. If, however, the voltages applied to the primary are distorted then the voltages delivered by the secondaries will be correspondingly distorted.

Grounded Neutrals.—It will be noted that in many cases the grounding of the neutral points of a transmission system limits the voltage strain to ground and the voltage which may be obtained across any transformer, and in such cases grounding would seem advisable. This is notable in the case of the star-system with grounds on transformer and generator neutrals. There is, however, a danger arising from this grounding which should be carefully considered. In case of trouble on the circuits, current may flow through the ground to the neutral; in thus flowing it will naturally take the path of least resistance, so that if telephone or telegraph lines, which have normally low resistance to ground, parallel the transmission circuit, the current will flow along these wires, often with disastrous results to the circuits.

Two cases of trouble are particularly liable to give these conditions:

First:—Where the neutral points of the high-tension windings of raising and lowering-transformers are grounded, the opening of one or two of the three transmission wires will cause currents to flow through the ground.

Secondly.—A high resistance ground on a transmission wire will partially short circuit a transformer and cause current to flow through the ground to the neutral.

Some plants have been able to operate satisfactorily with grounded neutrals; with others this grounding has caused great disturbance on telephone circuits, and in one plant it is reported that the blowing of a fuse on one of the high-tension wires put out of service the telephone systems in "ten counties." Thus, while grounding of neutrals may be permissible in certain localities it may not be allowable in others; and in laying out a plant it would seem to be advisable so to arrange the apparatus that it may be safely operated without grounding the neutrals.

An examination of the tables given on pages 1259, 1260, 1261, 1262, indicates that the delta-system is the one giving the

minimum chance of trouble. Under certain conditions, however, the star and star-delta systems will give satisfactory service.

The choice of a system of connections for any high-voltage transmission system is evidently a matter which should be carefully considered, account being taken of the possibility of obtaining excessive voltages under accidental conditions, the chance of trouble on parallel circuits, due to grounded neutrals, and the possibility of obtaining resonance when switching or under other similar conditions.

PRESIDENT SCOTT:—The question of grounding one point of a transmission line is a very important one, and it is one which has received a good deal of attention during the last few years. I remember when some engineers with whom I was acquainted went West to visit transmission plants, I asked them to look into that point particularly, and from the evidence which they got, and from the evidence that I obtained when I took a trip West some time ago, and from what I have heard since, I have concluded this—that some plants grounded the neutral, and its engineers considered it safe and would never think of running in any other way, while the engineers of plants which did not ground the neutral would never think of doing such a thing. It is an important question; it is partly theoretical, it is largely practical and one which is not yet settled. We should like particularly to hear from our western friends on this point. The subject is open for discussion.

MR. HAYWARD:—As you say, Mr. President, this has been a subject of discussion for a good while, as to whether to ground or not to ground, and our friend Mr. Nunn has been operating his lines grounded from the very start, but I believe Mr. Gerry is operating without ground. We, with our 16,000 or 17,000 lines, have operated with a double delta connection without any grounds on. The experiences we have had without grounds are, of course, that you may have a short circuit on one wire, and the wire down, and you could still keep running. Still, I believe—and this is only an opinion—that when we get up to any very high voltage, after all it is better to ground the neutrals and keep them grounded everywhere. It is better, I think, to avoid any chance of these extra high voltages that may occur, and I want to say very emphatically that they have occurred in practice, where some of the conditions mentioned by Mr. Peck and some mentioned by Mr. Blackwell have held. I therefore think that it is probably best to ground every neutral point. We are changing from a delta-delta connection to what will be a Y to delta connection and various other connections which we have not been running hitherto, simply because we are changing our voltage on the high tension lines from 16,000 to 28,000, and we intend to change our distribution in Salt Lake City from 2,300 volt to Y-connected 3,800 volt. Of course, we all recognize the difficulty of a single short circuit on a line with grounded neutral —or single breakdown on the line with grounded neutral—

means short circuit. Yet, after all, we have to recognize this, that our lines must be made so that they will not break down. There is just one point—the rise of potential mentioned in Mr. Blackwell's paper, page 1246—the conditions holding in Fig. 3 or 4, I don't know exactly which, actually occurred in testing a transmission line in 1897. The conditions were that we had 37 miles of line. We connected the two circuits on the pole line together solidly, making a line out and back of 74 miles. We got a delta-star connection and tried to see what the charging current on the line was. Having tried with the three switches closed, we then thought we would like to see what it would be with only two switches closed; and as soon as we got up to about 25,000 or 26,000 volts an arc jumped across the wires, 12 inches apart. Not only did it do it once, but it did it every time. That is the condition mentioned by Mr. Blackwell right here. If you get the conditions that are laid down here they will occur sooner or later in practice, and they will find out your weak spots.

PRESIDENT SCOTT:—Mr. Gerry, we turn now naturally to you.

MR. GERRY:—I do not know, Mr. President, whether I can add anything of value to this discussion. The selection of either the star or the delta system of connecting transformers is, to a certain extent, a matter of engineering detail. I say this for the reason that I believe satisfactory results can be obtained by the use of a star connection, although not quite as good results as by the use of a delta connection, on a transmission line. The points of advantage and disadvantage have been referred to generally by Mr. Blackwell and Mr. Peck. The points brought out by Mr. Peck are of great interest, but a plant can be arranged in such a manner as to avoid practically all the dangerous conditions outlined for a plain star system. It is possible to provide switching devices of such a nature that all three transformers will be cut out automatically, at the same time, in case of trouble with any one; or if a ground appear on the system, and this should always be done on a star connected transmission line, even if the neutral be grounded at the generators in addition to grounding at the transformers.

Mr. Peck, in introducing his discussion, says: "By the grounding of the neutral point of a transmission system, it is sought, first, to limit the strain from line wires to ground." Only a short time ago that was considered of great importance as reducing the strains on the insulation of the line. As a matter of fact, that does not limit the possible strain on the insulators to the pressure from wire to neutral. Even with all the neutrals grounded at the ends of the transmission lines, it is possible, owing to the resistance of the ground circuit, to have on the insulators the full line pressure between wires. In other words, even with a grounded neutral at the generators, it is possible locally, at points on the transmission line, to have the same pressure between the ground and any one line, that you have between any two wires of the circuit. Mr. Blackwell, in referring

to the advantages of a grounded neutral, in several instances states that in case of trouble, such as a ground on one of the wires, the result will be immediately to open the automatic devices and cut off the transformer coils from the line. Now, the same result can be accomplished with a delta connected system, by means of suitable automatic devices, and without throwing a short circuit on the system.

There are a number of operating advantages of the delta connection, one of which I will mention. A transformer may be cut in and out of service, in and out of delta, with very great convenience and with no disturbance of the system, and considerable operating advantage is thereby obtained, especially where the number of transformers is limited. It has just been suggested that one advantage of the star system is that it is possible to put in transformers connected in delta, and afterwards increase the voltage by changing over to a star connection. As a rule, however, I believe it would be better to arrange the switches for delta connection, and accomplish the desired result by double winding the transformers, operating the coils at first in parallel, and later in series.

MR. CONVERSE:—Mr. Hayward referred to the plant of the Telluride Power Company. I have had considerable to do with the transformers of that plant. It is an old plant, at least we consider it so now. I would say that those transformers were built for star connection on a high-voltage and a low-voltage, and we have had some results there. A great many things have happened there, and I would ask Mr. P. N. Nunn, Chief Engineer of the Telluride Power Company, who is here, to tell us something of them.

PRESIDENT SCOTT:—I had it in mind to call on Mr. Nunn very shortly. Mr. Nunn's work has figured largely in our INSTITUTE, both in papers which have been presented and in discussions from time to time; but Mr. Nunn himself, who has been so intimately connected with a great deal of this high-voltage and pioneer work, has not been very much in evidence. We are very fortunate in having him here.

MR. P. N. NUNN:—In our Utah system, star connected transformers with grounded centers have been the rule, although the initial transmission employed three-phase two-phase step-down transformers.

Transmission difficulties have been chiefly traceable either to outside interference with our lines, or to the opening of circuits, especially by fuses. The line system is rather complex, the main transmission consisting of duplicate three-phase, three-wire, 40,000 volt lines extending from the Provo to the Logan power house, a distance of approximately two hundred miles, through the several markets of Salt Lake Valley. These are divided into sections, and so arranged that a defective section will cut out without interrupting the whole system. Until recently we have been obliged to protect these sections, as well

as our generating and substations, with fuses and to switch at the same points with air-brake switches. Neither of these devices has been satisfactory. The blowing of a single fuse is often followed by the blowing of others, sometimes at distant points, and the opening or closing of switches sometimes produces the same result. It seems imperative that all wires of a circuit should be opened or closed simultaneously, and in this respect the automatic triple-pole oil-switches, with time-limit attachment, which are now being installed, should prove invaluable.

The mere opening or closing of circuits may have caused excessive rises of voltage, as we certainly have had at times some abnormal rises. I recall clearly one instance when current jumped a full eight feet from a conductor to the steel framework of the roof of the station. This may have been due to atmospheric disturbances, although there were no indications of lightning.

From the first we found that a ground on one line did not short-circuit the generator, and noticed that the first indication of such a ground was the arcing of the current over the lightning arresters. Investigation of the conditions led to the discovery that we had full line voltage between the remaining lines and ground, which accounted for the disturbance on the arresters, and also full line voltage on the active transformers, instead of the normal 58 per cent. of line voltage. No transformers have ever been burned out due to this condition, and no serious inconvenience has been suffered so far as I know.

This plant has been in operation nearly six years, employing as stated, star-connected, grounded center transformers and on the whole has been, I think, a pronounced success. Whether the difficulties mentioned have been aggravated by the connections of the transformers, or whether we would have suffered less with delta-connected transformers, I do not know.

PRESIDENT SCOTT:—I would like to ask Mr. Nunn about one point. You have grounded the central point of the high-tension system. Is the central point of the generator grounded primarily?

MR. NUNN:—The central points of both low and high-tension winding of the step-up transformers are grounded. The generator winding is not otherwise grounded.

MR. THOMAS:—Mr. Blackwell's paper contains a statement on page 1246 which I think needs a little further explanation—the last paragraph:

"It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches, etc."

Of course this is true if we neglect all true energy losses in the system, but there is inherently linked with the condition which he speaks of here an energy loss which must necessarily limit this rise of potential very materially. That will probably bear a little further analysis.

The conditions of resonance at normal generator frequencies, as shown in most all these discussions, requires that the leading current to a transformer line pass through a transformer in one winding, the other winding being open circuit. The only way it is possible to get a high enough inductance to meet the condition for resonance is by means of iron in the magnetic circuit in the transformer. As we all know, there is a considerable true loss represented by the energy taken by an open circuited transformer—open circuited, I mean, in the other winding. In some designs I have looked over, this true loss is almost as great as the apparent loss, though not quite so great. In other designs the true loss, I presume, may be half as great as the apparent loss. Now, the resonance results from the action of the potential from some generating source, which builds up oscillations in the oscillating circuit. This generator must supply the true loss. If the true loss is nearly half the total apparent energy, taken by the transformer when connected across the mains,—I mean the total energy, now, considering impedence—then if we should by resonance increase to double this true loss by increasing the voltage on the transformer, no higher potential can be built up, because all the true energy supplied by the generator is absorbed. This can be made a little clearer by considering the formula which gives the result of the current in the circuit containing inductance, capacity and resistance when conditions are right for resonance.

$$\text{Resonance Current} = \frac{\text{General Voltage}}{\sqrt{R^2 + \left(p^L - \frac{1}{p\,c}\right)^2}} \times \text{Sin}\left(p\,t - \tan^1 \frac{p^L - \frac{1}{p\,c}}{R}\right)$$

This formula states that the current equals the potential applied from the generator, divided by the true impedence of the circuit, which can never be less than the ohmic resistance R. If this allows only double current on normal voltage, resonance can cause no greater rise. Since the ratio between the true loss and the apparent loss of transformers changes materially with changing induction in the iron, and when above saturation the magnetizing current goes up very fast in proportion to the true energy current turns, it follows that perhaps the resonant current may have to increase several times to cause a doubling of the true loss. This suggests another point if you have the proper frequency for resonance, before e.m.f. is applied, assuming normal magnetic induction in the iron of the transformer. Then if resonance builds up the voltage to perhaps three or four times normal potential, the induction of the transformer has also changed very materially on account of the greater magnetising

current causing a great lessening of permeability and a reduction of the inductance as a choke-coil. Consequently the natural frequency, of the generator, which should give resonance will perhaps be several times larger than before the rise of potential started. It is thus quite unlikely with this type of choke-coil that resonance would reach a very high value, even if it were not limited by the true loss. However, when the inductance through which the resonance occurred is not denied for a closed magnetic circuit, as in the case discussed, the true loss is a very small percentage of the total apparent energy and no low limit to the resonance rise can be thus assumed.

In regard to static resonance—I mean resonance at very high frequencies, where chok-ecoils without rim coils might have the proper resonance values—it seems to me there is little danger of a very considerable rise, because, so far as I know, there is no source of continuous, constant value alternating e.m.f. at a very high frequency. Most discharge we get are perhaps oscillatory, but they lose their intensity very rapidly, two or three oscillations, only, probably, having any where near the maximum values of potential.

I would like to ask Mr. Mershon, in the absence of Mr. Blackwell, whether Figs. 5 and 6 on page 1247 should not show a ground on either line A or C, or some form of unbalancing. As those stand, I do not believe that resonance can occur. For instance, in Fig. 5, we have the natural tendency when the generator excites the lines for changing current to pass from B to A and from B to C, but these currents will be equal if there is no unbalancing, and since they pass in opposite directions through the halves of that idle transformer, there would be no choking effect except the small amount due to the magnetic leakage of the transformer. In Fig. 6, the natural tendency is for the charging current to pass from A to C, and even if the line B is connected at the middle point of the transformer, it is naturally at earth's potential and would never receive any charging current at all. Of course, if either line is then balanced or grounded there then appears a condition for resonance. Am I right in this conclusion?

MR. LINCOLN:—Just one point; I was going to mention a number, but Mr. Thomas has got in ahead of me on the others. One point struck me in connection with the statement of Mr. Blackwell, that theoretically 100 times normal potential was possible in a condition of this kind—resonance. In that connection I was very much interested in reading a contribution by Mr. M. I. Pupin, contributed to the TRANSACTIONS of this INSTITUTE in 1893, in which he showed how very difficult it was to maintain resonance with iron circuits. He showed that resonance, where there was no iron in the inductance, was very marked, but as soon as iron was introduced into his coils the difficulty of obtaining resonance conditions became extremely marked and very difficult to obtain; and that same condition

would, I think, apply here, where you have iron in the circuit of the choke-coil, and would prevent a rise in voltage anywhere near approaching that stated by Mr. Blackwell.

MR. PETER JUNKERSFELD:—In Chicago we have been operating a 4-wire-3-phase-60-cycle overhead system with a grounded neutral for about three years. The generators are star connected, and the common point is connected to the ground. It has been very successful from the start. We, however, ground in the station only, and do not ground any other point of the primary system. The neutral, on the secondary of transformers, is also grounded.

In our underground system, which is operated at 9,000 volts and 25 cycles, we likewise operate now with the grounded neutral. For the first four or five years development while the voltage was only 4,500, we had step-up transformers and they were connected in delta, but the next step beyond that was to double the voltage to 9,000 and install line voltage generators, which have been operated with the grounded neutral. There is one thing though that we have discovered, or rather which has been brought to our attention very forcibly. That is, the necessity of doing away with single-pole switches and fuses, and things of that sort. We have nothing but straight 3-pole oil-switches. We have no plug change-overs or fuses or single-pole switches. Those have all been done away with, and we believe it is very necessary to do so.

I might say that a great many of the conditions that are laid down here by Mr. Peck and Mr. Blackwell, as Mr. Hayward very forcibly brought out, do occasionally occur in practice, and that is something which needs a great deal of attention. As regards the delta or star-connection, in our experience we have found that the number of transformer troubles are after all comparatively few. In six years I can recall only four, possibly five, cases of serious transformer trouble in substations. With the increase in the number of transformer and rotary converter units feeding an interconnected network, we have come to the conclusion that the advantage of having delta-connected transformers in order to be able to cut out one of the bank and operate with two, is not very great. In the earlier history, when our installations were small and few in number, it was an advantage to have the delta-connected outfit, but with a larger number that advantage disappears, and to-day we are installing Y-connected 3-phase transformers, the idea being that these transformer accidents occur very rarely, and when they do occur a whole unit is usually shut down, in any event for a short time, and we can then just as well afford to have it shut down until such time when the whole 3-phase outfit can be replaced.

MR. MERSHON:—Mr. Gerry said something in regard to automatic means for cutting banks of transformers free on both sides. That would mean reverse circuit-breakers, and it would mean not only reverse circuit-breakers, but it would mean 40,000 or

50,000-volt circuit-breakers. Mr. Gerry knows something about automatic circuit-breakers for 40,000 and 50,000 volts. I would like to hear from him in regard to that.

MR. GERRY:—My remarks just now were intended to indicate that with proper arrangements, either the star or delta connection might be used with good results. If star connections are used on high voltage transformers, in fact on any transformers, it is desirable, in order to obtain proper safety, to have devices which will open all three legs of the circuit at one time, but if the delta-connection be employed, you may use single-pole switches. For this and other reasons, up to the present time, I have always considered that there were advantages in using a delta-connected system. Single transformers may be conveniently switched into and out of service; single-pole switches may be employed if desired and at the same time all those excessive potentials mentioned by Mr. Peck will be avoided, and resonance will not be likely to result. In other words, a plain delta is at once a flexible and safe arrangement to adopt.

In reference to high-tension circuit-breakers for transmission lines, the time is coming, if it be not here already, when an oil-switch can be obtained, together with reverse current and overload operating devices for any voltage and capacity, which will open all three legs of a circuit. Mr. Nunn touched upon this subject just now, and it is of great importance, especially with a star-connected system. Whether the star connection is the more desirable is another question, but I do not consider it vital in connection with operation, if proper precautions are taken. I do, however, consider the proper arrangement of switches, with either the star or the delta, a very important problem in connection with the system.

MR. A. L. MUDGE:—Page 1244, lines 16 and 17, the words "And the other two still deliver 3-phase power up to their full capacity, *i.e.*, two-thirds of their bank," should read, I think, as follows: "And the other two still deliver 3-phase power up to 86.6% of their full capacity, *i.e.*, 57.7% of their entire bank."

MR. J. E. WOODBRIDGE:—The special case of high-tension distribution of power for the operation of rotary converters brings up some considerations not mentioned in Mr. Blackwell's Introduction.

In distribution of this kind the secondary voltage of the step-down transformers is so low that there is no advantage in a Y-connection of the secondary coils. In fact, this would prove a positive disadvantage. For this reason a delta connection of the secondary windings is to be preferred for 3-phase converters. With the primary windings connected Y and the secondaries delta, operating synchronous machinery, there is no instability of the neutral. While it is true that a Y-delta connection of three transformers with no neutral lead throws the whole bank out of service if one is disabled, the grounding of the high-tension neutral of both the step-up and step-down banks

gives a radically different condition. With this connection one transformer of the three may be taken out of service and the remaining two will continue to deliver 3-phase current just as will two transformers connected delta-delta on a 3-phase system. It will be noted that when one transformer on a Y-delta connection with grounded neutral is taken out of service, one of the three line wires is also open-circuited. Thus not only does this connection allow service to be resumed with one transformer crippled, as soon at this transformer can be disconnected, but it allows service to be continued with one line wire in trouble, either broken, crossed with another wire, grounded or attached to a punctured insulator. It has often been claimed for the delta-delta connection of transformers that the ability to operate on two in case of trouble with the third is a great advantage. There are now in operation in this country many railway distribution systems with lines of moderately high-tension, 10,000 to 15,000 volts, put up on trolley-supporting poles along the right of way, which frequently is the public highway, with many trees and many turns, and lacking the substantial and carefully worked out details of the lines of heavy transmissions. These railway distribution plants, so built, are subject to unavoidable line troubles many times more numerous than transformer breakdowns. It seems to the writer that any connection of the transformers which allows operation with one line wire in trouble is much more valuable in such cases than any which simply provides for transformer troubles.

The drop on a 3-phase line with grounded neutral is increased just 50 per cent. when one line wire is thrown out of service, the other two being used on Y-delta connected transformers; this being based on the assumption that the ground or track return has a negligible resistance in the high-tension transmission. The writer has operated a railway substation in this way on two wires, starting a rotary converter as an induction motor by means of alternating currents applied directly to its armature, and carrying the load with two wires in service with no apparent difference in the operation from the usual results obtained with all three wires in service. In fact, much to the writer's surprise, there was no apparent effect on the telephone line which was on the same poles with the high-tension line for several thousand feet, one of the three high-tension wires being completely disconnected at both ends. At one time while operating in this way the transmission line became reduced to one active wire and ground, owing to the melting out of a temporary low-tension connection. The substation continued to carry its load and the trouble was not noticed for some time.

It is also of interest to note in this connection that 6-phase rotary converters supplied from diametrically connected transformers will start and carry load satisfactorily when supplied with power on two diameters only. With a Y diametrical connection of the step-down transformers and with a grounded

neutral the cutting out of one transformer would of course reduce the supply of the 6-phase converter to two diameters. It is almost needless to state that a 6-phase converter with double-delta low-tension connection would operate satisfactorily on two transformers.

Referring somewhat more in detail to the advantages and disadvantages of a grounded neutral, an investigation of the action in case of a punctured or broken line insluator is of interest, as most of the serious line troubles come from insulator breakdowns causing the burning off of cross-arms or pole tops which frequently results in complete shutdown. With no ground on the neutral, the puncturing of an insulator generally manifests itself as a ground on the system. To guard against burning of cross-arms or poles, it is possible to solidly ground the faulty phase, thus removing all electromotive force from the faulty insulator, but this method seems open to the objection that if one insulator will break down under the Y voltage of the system, it is inadvisable to subject two-thirds of the total number to nearly twice this voltage. Some lines are now being built with a fourth wire with switching arrangements at each end of same, so that in case of trouble on one wire the fourth can be connected into circuit in place of the faulty conductor. With a grounded neutral the question arises whether a broken insulator would cause sufficient leakage to open the circuit through overload, or would burn off cross-arm or pole-top without giving previous notice to the station attendants. A ground wire on the poles electrically connected to an iron pin in each insulator would make a short circuit of each insulator breakdown, and would prevent burning off of pole tops. With instantaneously acting automatic switches it would also prevent what is sometimes worse; *i.e.*, the burning apart of transmission wires and dropping of same across other circuits or to the ground.

Another factor that is affected by the grounding of the neutral is the protection against lightning. On a line with no ground on the neutral it is essential to have enough gaps to prevent a discharge under the full rated voltage between wires. This voltage is applied when one corner of the circuit becomes grounded. It is also necessary to provide enough resistance in each branch of the discharge path to prevent an arc holding when a discharge occurs under this votlage. With grounded neutral the maximum voltage between any one wire and ground is reduced nearly 50 per cent., allowing material reduction of the number of gaps and resistance in the discharge paths.

From the above considerations the writer believes that extra high voltage systems, that is, those with working pressure between wires of over 25,000 or 30,000 volts, should have the high-tension windings of their step-up and step-down transformers Y-connected with the neutrals grounded.

(COMMUNICATED AFTER ADJOURNMENT BY DR. LOUIS BELL.)

NOTE ON MR. BLACKWELL'S PAPER.

It should be noted that the Y systems, which are immensely

valuable in saving copper, also entail some additional care, as is the case with all copper-saving connections. In practice I have found that mixed delta and Y connections are desirable and tend to steady the regulation. I believe in the grounded neutral as a safety measure, but sources of accidental grounds should be followed up rigorously and carefully eliminated. In using Fig. 1, this is especially necessary, and it is a good thing to ground through light fuses or lightly set circuit-breakers, but one usually has to ground this system since its main use is in making long runs where high voltage lines are barred, and the Fig. 1 connection carries one below the prohibitive restrictions placed arbitrarily to allow old arc machines to run while blocking modern distributions.

(*After Recess.*)

PRESIDENT SCOTT:—We will now descend from the air above to the earth beneath and take up underground work.

We will first have the paper by Mr. Fisher, of the Standard Underground Cable Company. "Electric Cables for High Voltage Service."

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1st, 1903.

ELECTRIC CABLES FOR HIGH VOLTAGE SERVICE.

BY HENRY W. FISHER.

In the early part of the last decade there was a general belief among electrical engineers that rubber-covered cables would be used almost exclusively for high-voltage service and paper-insulated cables for comparatively low voltages. With the improved manufacture of the latter, opinions have changed so that some engineers prefer paper to rubber, stating that in their experience the life of paper cables is longer than that of rubber cables. To account for this they believe that the strain caused by very high voltages gradually deteriorates the rubber by some kind of electrolytic action, or by a purely physical action, or by a tendency for static discharges gradually to penetrate farther and farther until a breakdown occurs. In substantiation of their claims they give instances where rubber cables have broken down one after another in service without any apparent cause. On the other hand, there are engineers who claim that they have operated rubber cables at high voltages continuously without any trouble. The ability of a rubber-insulated cable to withstand high voltages depends upon the ingredients entering into the composition of the rubber compound. The dielectric strength to resist electric pressure becomes greater within certain limits with increased percentages of pure Para or other high-grade rubber; and there is good reason for believing that when lead-covered cables are employed, the life of rubber-insulated cables is lengthened with increased percentages of such rubber. This subject should naturally be treated under three headings:

First: Manufacture of cables.
Second: Installation of cables.
Third: Operation of cables.

First: *Manufacture of Cables.*—In the manufacture of paper-insulated cables for high voltages, great care has to be exercised in selecting the right kind and quality of material, and also in the methods of construction and impregnation of the paper with insulating compound. The most experienced engineers now realize that cables saturated with oily compound can better be handled without injury to the dielectric, and also resist better high voltages. The use of oily compound is, however, accompanied with lower insulation resistances, and consequently many engineers who think they are adopting the best practice by specifying several hundred megohms per mile, are in reality inviting bids on an undesirable type of cable. The best cables either with paper or rubber insulation should be able to resist comparatively high voltages for an extremely short period of time. Such voltages are obtained at the time of making or breaking the circuit, or during short-circuits. To illustrate: If a cable of inferior material and construction be subjected to a gradually increasing voltage till a breakdown occurs, and then after removing the burnt-out part the operation be repeated, a second breakdown will almost invariably occur at much lower voltage than at first, showing that the cable was injured by an impulsive rise of voltage at the time of the first burn-out. With the best cables the difference between successive voltages applied as above is much less than is the case with inferior cables, and at the same time the former withstand very much greater voltages for the same thickness of insulation. If the question of expense is not a consideration, paper insulated cable can be made of remarkable dielectric strength. On one occasion the writer designed such a cable with a thickness of insulation capable of ordinarily withstanding 16,000 volts. Extraordinary care was exercised in the manufacture of this cable, and when tested 48,000 volts were required to break it down, and during successive tests the voltages applied scarcely varied 1,000 volts from the above figure, showing a very great uniformity. Such a cable would have a greater dielectric strength than that of ordinary rubber cables, and at least equal to that of rubber cables with high percentages of Para, and would cost fully as much as the latter.

In the manufacture of rubber cables, care has to be used in

selecting the best and proper materials; and the work of mixing them and masticating and applying the rubber must be done uniformly well, and the process of vulcanization must be carried on at the right temperature and for the right length of time to suit the particular compounds. After being made, all high voltage cables should be subjected to the usual test for insulation resistance and electrostatic capacity, and also to voltage tests of double the normal working e.m.f. Even if this test is not specified the manufacturer should apply it for his own protection.

Second: *Installation of Cables.*—This work must be done by well-trained men, as a small amount of carelessness may mean much trouble and expense. When the cables are pulled into ducts great care must be exercised to prevent abrasion of the lead cover, and no sharp bends must be made because in so doing the insulation may become injured or cracked. It is advisable not to pull paper insulated cables into ducts during extremely cold weather, because of the possibility of cracking the insulation. If such work of installation has to be done, the reels of cable should be kept in a warm place over night, or else put under a tent for a few hours and kept warm with plumber's furnaces placed so as not to overheat the cable at any point.

The work of jointing the cables must be done by good jointers, who are in turn carefully watched by an experienced foreman. Different companies make different forms of joints, but after a reliable one is adopted the work should be systematic and according to definite directions in all particulars. By so doing, remarkable records of perfect workmanship have been made. After complete installation each cable should be subjected to double the working voltage, but this voltage should not be applied or broken suddenly because by so doing unnecessary strains would be imposed upon the cable.

Third: *Operation of High Voltage Cables.*—This is a subject that could better be presented by the operator of the electric light and power plants where cables are employed. However, as one of the objects of this short paper is to invite discussion, it may be well to state that a perfect protective device for cables and auxiliary apparatus would lessen to a very large extent the troubles of the operator incident to impulsive rises of voltage from switching and short-circuit. On several occasions and in different power houses, discharges have been seen to take place over the surface of switchboards at the time of short-circuits in cables, transformers, switches, etc. On some of these occasions

the rise in voltage necessary to make said discharges was estimated to be about four times the normal working voltage. At such times the original cause of the trouble cannot always be ascertained because frequently cables are burned out in several places, and transformers and apparatus injured at the same time. This kind of phenomena seems to be more prevalent and dangerous where air-lines connect with cables. It will therefore, be seen that an efficient device which would protect cables and accessory apparatus from such excessive rises of voltage would be of incredible value to operators.

The question of the carrying capacity of cables is often not considered as carefully as it should be. When a great many cables all carrying normal currents are in one duct-system, the middle and top ones are apt to become very warm. The difference between the temperature of the conductor and that of the duct may be nearly as great as the difference between the temperature of the duct and that of the surrounding air, although generally speaking the former is the least. The carrying capacity of cables as frequently recommended is entirely too great when many cables are in the same duct-system.

There is a very great difference in the radiating power of dry and wet-ducts, and in the heat conductivity of different soils, and so it is impossible to give set rules governing all cases. Under no circumstances should the temperature of the conductor be allowed to reach 90° Centigrade; and if twice the maximum difference of temperature between any duct and earth added to the temperature of the earth is nearly equal to 90° there is reason for apprehension.

The above remarks do not apply to rubber covered cables, which should never be heated to over 65° or 70° C.

Moreover is is not desirable nor economical to heat paper insulated cables to 90° C., and the only reason for mentioning this figure is because such cables can withstand this temperature for a considerable length of time without deterioration.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS.

BY PHILIP TORCHIO.

The following notes apply mainly to moderately high-tension systems as installed in large cities in the last few years.

(1) Independent vs. Parallel Operation of Feeders at Substations.

By proper selection of size of feeders and transforming units at substations, each feeder can be operated to supply normally an independent group of transforming apparatus. In case of emergency the same apparatus can be arranged to be fed from other feeders through an emergency bus. This arrangement of independent operation of feeders has in most cases the disadvantage of not allowing the full use of the copper investment at light loads, but it has the following advantages.

(*a*) The short-circuit current fed back from the substation bus bars into a faulty feeder is limited by the reactance of at least two sets of transforming apparatus. This will materially help the final clearing of the short-circuit.

(*b*) In rotary converter substations the independent groups of transforming apparatus can be fed from different bus bars or from different generating stations, thereby increasing the reliability of service.

(2) Testing of Cables.

(*a*) Periodic insulation tests are valuable as they furnish indications of abnormal conditions and often lead to the detection of faults on the systems. The instruments usually used in connection with insulation tests are a D'Arsonval galvanometer with

shunt, and a battery of from 70 to 100 volts. Periodic tests should be made at least once a week on each feeder, and oftener under abnormal conditions.

(*b*) High-voltage tests of dielectric strength of insulation should be carefully applied or possibly avoided entirely. Experience has demonstrated that failure of cable feeders are almost uniformly due to defective joints or mechanical injury to the cable. The record of all high-tension cable faults of a New York company for a period of five years is as follows:

LOCATION OF FAULTS ON HIGH-TENSION CABLES.

Made manifest by opening of circuit-breakers during operation.	Made manifest by low insulation test.	Reported by Line Inspectors.
1 in splice.	1 in splice.	1 injured in manhole by arc cable burnout.
1 nail driven into cable (external mech. injury.)	1 in splice.	
1 in sharp bend in manhole.	1 in splice.	1 damaged in manhole by A.C. lighting cables burnout.
1 in damaged sleeve (external mech. injury–cause unknown.)	1 leak of steam to cable end.	
1 in bend in small manhole.		1 damaged by outside parties doing subway work.
1 wet end of cable (external injury due to water leak.)		1 damaged as above.
1 wet end cups caused by steam (external mechanical injury.)		1 damaged as above
1 steam in substation (external mech. injury.)		
1 in splice.		
9	4	5

Note that of the nine faults made manifest during operation, five were due to extraneous mechanical causes and four to defective installation.

The operating voltage of this system is 6,600 volts.

The lengths of high-tension cables in operation on December 31st of the first and last year covered by the record were 3.2 and 84.6 miles, respectively. The cables of this company have not been subjected to high-pressure test in subways.

This table shows that only four cable breakdowns out of 18 faults on high-tension cables could possibly have been prevented by having applied high-pressure tests to the cables originally. It cannot be determined how successful such tests would have been in other respects, as the testing strains might possibly have lowered the dielectric strength of the insulation at points otherwise perfectly safe for operating at the normal pressure. Note must also be taken of the fact that no failure of the cable proper has yet been recorded in this large system, now operating over 85 miles of high tension cables.

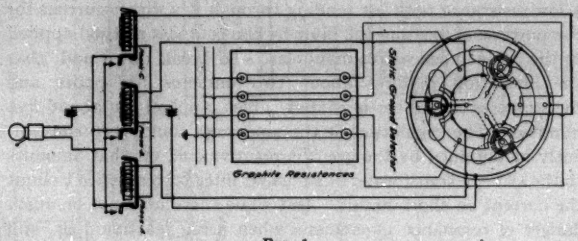


FIG. 1.

(3) INDICATORS AND PROTECTING DEVICES.

(*a*) Ground detectors with annunciator relay and drop-signal are desirable features of a high-tension switchboard equipment. The diagram (Fig. 1) shows an arrangement for a three-phase installation.

(*b*) Grounding of the neutral of high-tension generators is advocated by many engineers, and apparently it has given satisfaction wherever it has been tried. The objection to the heavy short-circuit current from one leg to ground has been overcome by the suggestion of grounding through a non-inductive resistance, thereby limiting the short-circuit current to a pre-determined amount. The experience of the companies so operating will be of great value.

(*c*) SPARK ARRESTERS.—It seems impossible always to guard

against the appearance of high voltages due to sudden change of load, grounds, short circuits, etc., and, especially in the latter case, spark-arresters will greatly increase the safety. These devices are preferably connected "delta" on systems without grounded neutral and installed at the generator end as well as substation end of every cable and at every other place where the cable is looped into a substation or joins an overhead line.

(4) Apparatus and Methods for Care of Cables.

A new cable should not be connected to the main bus bars without being previously tested with full working pressure. This is sometimes accomplished through a suitable transformer properly fused or by inverting a rotary converter with a fuse on the low tension side.

A defective feeder often requires the application of high voltage for breaking down the defective insulation and creating a low-resistance path for sending through it a direct current for the purpose of locating the fault by the compass method applied to the cable in successive manholes. To break down and char the insulation requires about two amperes for paper and five amperes for rubber-insulated cables, applied for about five minutes. The regulation of the amperage could very conveniently be obtained by the use of a reactive coil, or what amounts to the same, a transformer of sufficient internal reactance to limit the current on short-circuit. But while there may not be much danger of resonance phenomena when using reactive coils, still there is some danger and it is, therefore, safer to limit the short-circuit current by resistance. Fig. 2 shows the connections of a rheostat intended to limit the short-circuit current to 2½ and 5 amperes at 6,600 volts.

(5) Rules.

In a large system it is important to devise a set of rules for the guidance of the men in the different departments. These rules must be rigidly complied with so as positively to eliminate any danger to men making tests or repairs to cables or switchboards.

(6) Maintenance.

It is not feasible to estimate accurately the life of high-tension cables and what will be the cost of maintenance after several years' installation. The cost of repairs for the first years is merely nominal, and the only other items of maintenance are the expenses for the periodic inspection and testing and minor details.

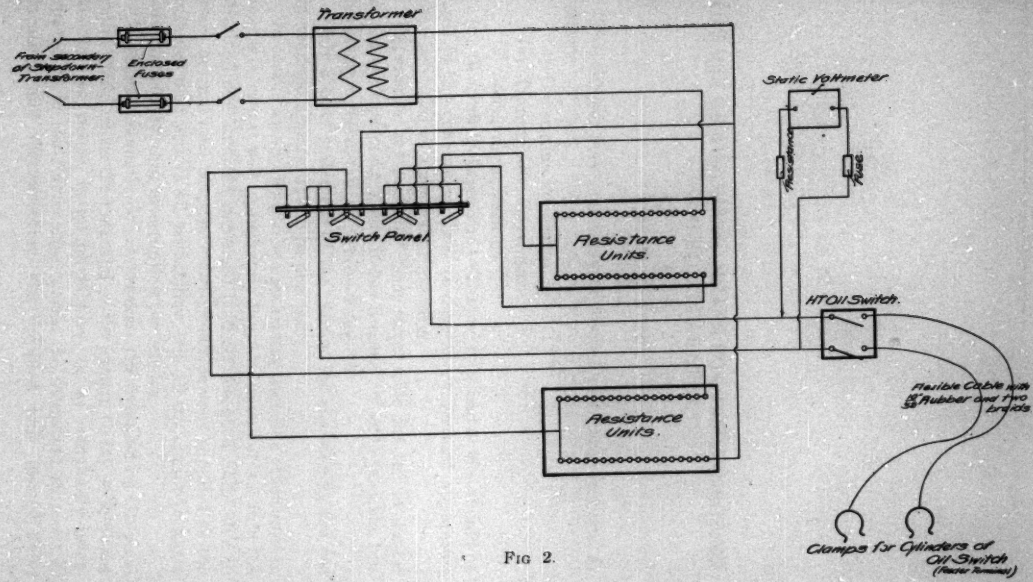

Transformer
From Secondary of Step-down Transformer.
Enclosed Fuses
Static Voltmeter
Resistance
Fuse
Switch Panel
Resistance Units.
HT Oil Switch.
Flexible Cable with 5/8" Rubber and Two Braids
Resistance Units.
Clamps for Cylinders of Oil Switch (Frame Removed)

FIG 2.

To be presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS.

BY H. G. STOTT.

This subject may preferably be divided into three sections, as follows:

(*a*) Generating apparatus.

(*b*) Transmission apparatus.

(*c*) Receiving apparatus.

(*a*) *Generating Apparatus.*—That no overload device should be used in the generating plant to disconnect disabled apparatus, may be stated as a general proposition.

Experience has probably been responsible for the evolution of the art to a point where it has become not only possible, but necessary to eliminate all overload devices.

Only a brief statement of the reasons for abandoning the use of overload apparatus will be necessary.

In case of an accident to one generating unit, the other units in multiple with it will immediately begin to force current into the disabled one, and the increased load on the good units, due to their normal load plus the short-circuit current supplied to the crippled unit will, in all probability, trip all the circuit-breakers simultaneously, thus interrupting the service.

Without automatic circuit-breakers the overload on the good units would cause the potential of the system to fall so low that the service would, in all probability, be as completely interrupted as in the former case, unless the attendant succeeds in locating and disconnecting the crippled unit immediately.

Should he fail to do so, the service will inevitably be interrupted, and a great deal of damage done to the crippled unit by the current from the good machines.

It is then evidently necessary to have some means of discriminating between a current coming out of the machine and one going into it. Modern apparatus can safely carry 200 per cent. or more load for a few minutes, but if a unit has become crippled it will immediately cease to be a generator and become a receiver. All that is necessary to do then is to install on each generator a suitable circuit-breaker which will operate *only* when the direction of flow or energy through it is reversed.

This type of safety device has been developed for both D.C. and A.C. apparatus so that it operates quite satisfactorily.

As an additional precaution in large plants, a second reverse-current relay should be installed which will merely light up a letter or number in front of the operator so that in the event of the failure of the first automatic device the faulty machine may be quickly disconnected by hand. These reverse-current relays should have a time-element and current-limit attachment, which should be set for not less than three seconds, so that a slight reverse current, or one of momentary duration, such as is liable to occur at the moment of multiplying, will not operate the circuit-breaker.

(*b*) *Transmission.*—When transmitting power through overhead and underground cables, it is essential to successful operation to be able automatically to disconnect the feeders from (1) the generating station, and (2) if there are duplicate transmission lines, from the receiving station.

(1) At the generating station this should obviously be done by an overload circuit-breaker whose operation is delayed by a time-element which may be set at from one to ten seconds according to the local conditions.

This is all the protection necessary or desirable where only one transmission line exists.

(2) With two or more transmission lines in multiple, an entirely different set of conditions exist as in case trouble develops in one, current will be fed back from the receiver end into the fault through the good feeders; the result will be that all the feeder overload breakers at the generating station will trip, thus shutting down the entire line and, in all probability, shutting down all synchronous receivers on the system, due to the resultant fall in potential.

Reverse-current relays at the receiver end of the feeders operate satisfactorily, provided the fault is not severe enough to drop the potential.

If, however, the fault amounts to a short-circuit the potential at the receiver end will fall so low that the potential coil of the differentially-wound relay will not receive enough current to enable the relay to operate.

Reverse-current relays on the receiving end of feeders are not as yet to be depended upon, but recent improvements give promise that we may soon expect to find a satisfactory solution of this important problem.

When only two feeders are in use a method devised by Mr. L. Andrews, of England, seems to be very satisfactory. At the receiver end the two feeders are connected together through a choking-coil wound entirely in one direction. The current is drawn from a tap in the centre of this winding. Under normal conditions the feeders supply equal current through each half of the winding to the tap, but as the currents pass in reverse direction through the winding the resultant flux is *nil* and, therefore, the resultant inductance is *nil*, the only loss being that due to the ohmic resistance of the coils.

Should a short-circuit occur in one of the lines, the current from the other line will flow through both halves of the reactive coil in the same direction, thus producing a strong choking effect and limiting the current to an inconsiderable amount.

As the overload circuit-breaker on the faulty feeder at the generating station will trip immediately, it is then only necessary for the attendant at the receiving station to open-circuit the section of the reactive coil connected to the faulty cable and short-circuit the other half connected to the good cable. This device, I am informed, has given excellent results in England, but for obvious reasons would not be suitable for more than two feeders.

Where possible, the safest plan at present is, in the writer's opinion, to run the feeders entirely separate at the receiving end, only putting the D.C. end of the rotaries in multiple; or in cases where low tension alternating current (2000 volts or less) is supplied, putting the secondaries in multiple. If, under these conditions, reverse-current relays are installed at the receiving end of the feeders they will operate very satisfactorily as the reactance of the rotaries and transformers will be sufficient to limit the reverse current in the faulty cable, thus allowing the

reverse-current relays to operate as there has been no serious fall of potential.

The greater the number of feeders used between the generating station and the substation the better this method becomes, as, for instance, with two cables a fault in one will only reduce the capacity 50 per cent. until the operator can synchronize all the apparatus, which was running on the faulty cable, and as the apparatus and converters will continue to run at full speed only a few minutes will be necessary to synchronize on the good feeder, which will in the meantime carry the whole load, so that no interruption to service will occur. With three cables this would mean a loss of capacity of 33.3 per cent., and with four cables 25 per cent., etc.

(*c*) *Receiving Apparatus.*—This should be treated in exactly the same way as the generating apparatus, namely; use reverse-current relays *only* to operate the circuit-breakers on the rotaries, etc., and use time-element overload relays only on the low-tension feeders leaving the substation.

The above remarks apply generally to both D.C. and A.C. apparatus, with the exception of the part devoted to transmission apparatus, which, of course, only applies to A.C. transmission.

Discussion of H. G. Stott's Paper on "The Use of Automatic Means for Disconnecting Disabled Apparatus."

By W. F. Wells.

Mr. W. F. Wells:—Recent experience with 6,600 volt, revolving field apparatus in central power station practice has proved that automatic disconnective devices are not necessary in order to insure reliable operation of the system to which current is supplied and that capable operators with good judgment can handle any cases that may arise better than automatic devices could be expected to operate.

The instruments and controlling devices on each generator should be placed close together, and their positions so related that there could be no possible chance of the operator when noting the indication on the instrument of one generator, becoming confused and by mistake opening the switch of another machine.

In the station referred to each generator is equipped with an overload relay whose secondary is connected to a red lamp only, and the following indicating instruments, wattmeter, power-factor indicator, field ammeter, voltmeter and two ammeters.

The first indication of any trouble is generally a drop in bus pressure, unusual noise from the generators, or lighting up of the overload lamps. A quick survey of the instruments enables the operator to determine if the trouble is on the generators or feeders. If on the generators, the wattmeter or power-factor indicator shows if current is reversed in any one of them, and the field ammeter shows if the reversal is due to open field circuit or loss of motive power. The character of the swing or vibration of the needles will show whether the trouble is due to some accident affecting the angular velocity, such as break in valve motion, or if it is due to faulty governor, cut off of steam supply or broken vacuum.

After a short experience in any such station equipped similarly to the one mentioned, the operator is able almost immediately to locate the cause of the trouble, and if he thinks advisable, open the circuit-breakers before any automatic device would operate, if properly protected by a time-limit element.

During the past eighteen months eight generators have been operated a total of 25,000 hours and a careful analysis of every accident or mishap that has occurred has failed to show any necessity or even desirability of automatic disconnective devices. It is almost needless to add that the station was free from accidents that might have been caused by faulty operation of unreliable devices, and there was no expense incurred for maintenance and repairs of such devices.

In the transmission apparatus, it has been found best to set the time-limit overload relays on the feeders in the generating station for two seconds and at about two and one-half times normal load.

During the entire time that the station has been in operation, a period of nearly two years, it has always been the practice to

run the high-tension feeders on what Mr. Stott refers in to his paper as the safest plan; *i. e.* entirely separate at the receiving end, only putting D. C. ends of the rotaries in multiple. But as practically all the substations are equipped with large storage batteries, which are also in multiple with the rotaries, it has been found best to operate without reversed-current relays, but depend on the operator in the substation opening the circuit-breakers when necessary. Here as well as in the generating station, the operators very quickly learn to read from their instruments the nature of the trouble, and the disturbance to the system caused by any accident is always less than it might have been had automatic devices been depended on.

In the substations, the receiving apparatus converts the alternating current to 260 volt direct current and here the only automatic device is an overload-relay on the high-tension feeders, and a centrifugal device which opens both alternating current and direct current switches of the rotary if its speed approaches too close to the danger limit. On the direct current feeders there are no automatic devices.

In general, on the entire system there are in use no automatic disconnective devices except those operated by the time overload relays on both ends of the high-tension feeders, and by the centrifugal speed limit device on the rotaries in the substations.

DISCUSSION OF H. G. STOTT'S PAPER BY MR. CARL SCHWARTZ.

MR. CARL SCHWARTZ:—As to the reverse-current relay for the generator circuit, I think that this relay should operate a lamp and then maybe in addition a bell signal in order to call the attention of the operator, so that he could take as quickly as possible suitable steps to bring the load back to the generator or disconnect this unit if it is unable to work. A reverse-current relay, opening the generator oils-witch, is in that case not very essential and could be left out entirely; but if it is applied it should be provided with a time and current-limit relay. The exciter generator circuit must contain a reverse-current circuit-breaker acting as soon as the generator begins to run as a motor, the supply of the generator field being maintained by a storage-battery.

Referring to the transmission lines, I would say that at the generator end, overload relays with a time limit device will be generally sufficient. It is important that the overload as well as the reverse-current devices for the feeder lines are connected to each phase, as burnouts between one conductor and the lead cover, not affecting the other phases of a three-conductor cable line, may occur. I refer here especially to the star-connected system.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON "THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS," BY MR. EDWARD P. BURCH.

MR. EDWARD P. BURCH:—Referring to the testing of insulation of high-voltage cables, the writer would add his experience with

two very successful 12,000 volt three-phase cables, one 9.5 and one 7.0 miles long, used by a Minneapolis company for three and five years respectively.

Experiments were made on short lengths of these paper cables by stripping off the lead sheath and partly immersing them in water, the full potential being on the three legs of the tr-iphase cable. It was found that it usually took several days before water impregnated the paper insulation to such an extent as to cause a short circuit between the legs.

Now most of the cable faults are due to mechanical causes such as a damaged lead sheath or to chemical deterioration of the sheath due to electrolysis from a direct current circuit. In both cases moisture finally, from a day to a week, works through the paper insulation and a cable break occurs. Manhole inspection for the exact location of electrolytic trouble generally proves valueless. Mechanical troubles at or between manholes are generally classed as " accidents."

Tests of value were regularly made on these 12,000 volt cables, using 600 volts direct current. The scheme is to charge the cable legs and then to note the electrostatic discharge through an ordinary Weston direct current voltmeter. The cable terminal switches were of course open at the station and at the sub-station. If the electrostatic discharge is large, one may safely conclude that the cable is not in bad condition. If the discharge, as indicated by the swing of a voltmeter needle, is weak, this is due to the fact that the charge has leaked off through faulty insulation. The indications are, in general, reliable.

In railway power houses regular testing, between 2 and 5 A. M., thus furnished indications of the condition of the cables. It is of some real value to an operator to know that a certain cable is weak and may blow out.

Ground detectors sometimes give negative results. The indications on the scale of the commercial switchboard instrument are too rough to be of great value.

Cable testing sets of the D'Arsonval galvanometer type are generally too sensitive for power station work.

High-voltage tests of cables in service are considered of doubtful value.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON " THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUD SYSTEMS," MR. W. G. CARLTON.

MR. W. G. CARLTON:—The experience of the Chicago Edison Company with its high tension-three-phase cables has been similar to that of the New York Company mentioned by Mr. Torchio. At present they are operating about 45 miles of three conductor cable at 9,000 volts. The first of these cables was installed about five years ago. The voltage used at first was 4,500 but about one and one-half years ago it was changed to 9,000.

There have been seven cases of trouble on these cables: Four were caused by mechanical injuries to cables in manholes; one

by a burnout on an adjacent cable; one by a defective joint, and one by electrolysis causing a hole to be made in the lead sheath of the cable. With the exception of the defective joint none of these troubles would have been avoided by using high pressure tests on the cables.

The neutral points of the high-tension generators are grounded direct, no resistances being used to limit the flow of current. Two cases of trouble already referred to, one due to mechanical injury and one to electrolysis, resulted in one conductor of the cable burning to ground, and the other two being left in good condition. One of these cases occurred within 3,000 feet of the generating station. The overload coils on the oil-switch worked and cut out the line. Rotaries in two large substations were running from this line but they merely dropped their load and did not feed back into the cable. Immediately after the trouble occurred the line tested clear and 9,000 volts was applied for about 10 minutes. When the trouble was located it was found that about 6 inches of the copper in one line was gone, and there was an irregular shaped hole in the lead approximately three by six inches.

The second case of trouble occurred about four miles from the generating station and was manifested by a motor generator operating from this line, making a peculiar noise. It was afterwards found that this was due to its running as a single-phase instead of a three-phase motor. The operator at the generating station had not noticed any trouble. One copper was found burned open and there was a hole in the lead approximately the size of a half dollar.

These two cases of trouble are possibly unusual in that very little damage was done. I believe however if we had been operating without a grounded neutral the chance would have been greater for more serious trouble owing to the displacement of the neutral that would have occurred.

PRESIDENT SCOTT:—We shall be pleased to hear from Mr. Eglin.

MR. WM. C. L. EGLIN:—Our experience is different from that of other large companies in that we use a higher frequency, and as we started with 60 cycle rotaries before they were properly developed, it necessitated the use of direct current circuit-breakers on the direct side of the rotary converters, for the reason that these rotary converters were installed in stations with storage-batteries and also with other similar units. With hand operation the current on the direct current side of the rotary would flash over before the operator had time to open the circuit-breaker, and with a large battery in the station it generally resulted in wrecking the rotary at least wrecking the brush-holders. There were very few of the brush-holders left after that flashing took place; so that we have used circuit-breakers on the direct current side of all rotaries since that time. If we had machines with effective bridges it is possibe we would not have

used the automatic circuit-breaker on the direct current side of the rotary.

The only other protective device is an automatic speed limit device to prevent speeding up beyond a predetermined speed.

One feature that I feel has not been discussed, and I was sorry it didn't have more discussion in connection with the paper last night, is the limiting of current on the high-tension feeder. I feel that with the growth of the size of generating stations and all of the feeders being run in parallel on a large generating station, we must provide some means for limiting the amount of energy that can be put in to any short circuit of a high-tension cable. Our own practice has been to subdivide the feeders at the sub-stations so that at the substation ends the feeders were not tied together. I think our operation has been much more successful since this has been done. We had conditions similar to those that are spoken of by the high-tension people; that is, that we had the cables break down when they were tied together at the substation end, and a number of other cables would break down for some unexplained reason. Last winter we ran through with all of our cables separated at the other end, and if a cable broke down, that was the end of the trouble; no other cable would break down due to the disturbance in the line during the time of the short circuit.

MR. MAILLOUX:—I think that the customer sometimes has to combat the zeal of the manufacturer's sales agent in such matters. The importance of doing away with automatic control of the generators is, I think, such that it should not be under estimated or passed over lightly. It is of great importance in central stations, and it is even of greater importance in relatively large isolated plants. Perhaps the first attempt made to dispense with it in a large isolated plant was in connection with the Astoria Hotel nearly nine years ago. In laying out the plant there I foresaw that it would not do at all to have the machines become disconnected just as soon as we happened to have a little overload, and that it was necessary to resort to some other means of dealing with overloads. We first tried to raise the limit by putting on larger fuses, and we foresaw that cases might occur even where that would not do. We finally resorted to the expedient of putting in an overload-relay, which operated, not to cut out the dynamo but to put on a red light and ring a big bell, the effect being to call attention of all the attendants to the fact that there was danger, while the red light would show the particular dynamo that was overloaded. It was found in practice, however, that even that was not a desirable thing to do, because it might excite a panic. The apparatus is there, but it was never used and they now depend on the operators entirely. There is a man whose duty it is to stand by all the time and see to it that no panic occurs. If there is any overload it is better to let the machine run up to 100 per cent. overload, if necessary, rather than take chances of having a machine become cut out and

cause a serious panic. You understand that in a place like the Waldorf-Astoria, where the load is comparable to that of a small town, with from 20,000 to 30,000 incandescent lamps and a motor load varying from 500 to 1,000 h.p., it is a serious matter. I am pleased to say that in something like eight or nine years only one or two interruptions have occurred, and one of those was due to the breaking of a steam pipe.

MR. MERSHON:—I would like to hear further from Mr. Torchio or his representative, Mr. Wells, in regard to a number of points. One is in reference to his statement at the bottom of page 1280, that only four cable breakdowns out of 18 faults in high tension cables could possibly have been due to defective installation. As far as anything in the table itself is concerned, it seems to me that nine of the faults there mentioned might have been shown by a voltage test. I should like to ask also whether it is the practice of the Edison Company to install cables and put them into service without giving them any more of a voltage test than one at normal voltage. In regard to the method, mentioned by Mr. Torchio, of keeping each set of apparatus consisting of cables, transformers and converters separate and distinct until the direct current bus-bars were reached, it seems to me that condition is undesirable because of the fact that you do not get the benefit of your copper on low loads. Under such conditions you must, as your load diminishes and you cut out rotaries and transformers, cut out also the cables to them so that you keep up to a certain point, a constant load loss on the cables that remain in service. I suppose that if it were possible to obtain a reverse circuit-breaker that could be depended upon to cut out a damaged cable, which would operate under very low voltage or at no voltage—it would be desirable to multiple the cables. I would like to ask Mr. Stott at this point whether he has gotten on the track of any such reverse relay, and whether he thinks there is any chance to have one in the future. His reply will I hope, bring Mr. Gerry into the discussion, as Mr. Gerry expressed himself a while ago as confident that such device was obtainable. If there is such device I would like to know about it.

I would like to ask Mr. Fisher whether he has made any investigation of the rise in the temperature of cables due to the difficulty of getting the heat from the cable out into the ground; that is to say, as to the fall in temperature that is necessary to force a watt across a given amount of duct and into the ground; whether he has gotten any results which would enable one to calculate, in a duct system, what with a given distribution of load in the cables, the temperature would be of, say, a cable in middle duct. I tried to get some information of that sort a while ago, and went just far enough to get the information that would answer for the particular installation I was about to make. The results were not very full and referred to a conduit consisting of a very few ducts. I should also like to know whether Mr. Fisher has any definite figures on the actual temperature at the conductor which large paper cables will stand continuously without injury.

MR. MAILLOUX:—I think that the maximum voltage limit of cables is one of the important questions. I meet with that question constantly in my practice, in cases where one wishes to run overhead but comes to pieces of property where we cannot possibly get the right to run overhead. I have had such cases in districts where rich men live, who seriously object to having overhead wires of any kind pass by or near their properties. In one case it happened that my clients themselves are the people who most objected. They were stockholders of the company, and owned it, and yet, though they understood fully the import ance of getting past, they did not want the lines run overhead. In some cases we have had to resort to very expensive underground construction in order to meet that difficulty. Now, as the radius of activity of such a station increases—as the territory expands on the outskirts—it becomes all the more important to be able to raise the voltage. I had a case which was started at 2,000 volts, which was intended to operate over a radius not exceeding two miles. At the end of two years we raised the potential to 6,000 volts and extended the radius to about 10 miles. We are now desirous of extending that radius to 25 miles. I may state incidentally that the station was designed for 500 kilowatts. It is now being transformed into a 6,000 kilowatt station. This gives you some idea of the growth of the system and of the difficulties which are likely to come up in connection with a station growing under those conditions. The problem with which we are confronted is, to what voltage shall we now step up? We shall probably operate at three voltages corresponding to three zones, a 2,000 volt zone, a 6,000 volt zone, which we already have, and a still higher zone. Now, shall that zone be 12,000, 15,000 or 20,000 volts? It seems to me that it is going to be limited by the limiting voltage at which I can get underground cables which will be reliable for good service. I have been told by some that these cables can be operated successfully at 10,000 volts; by others, as high as 20,000 I should like very much to hear from Mr. Mershon, from Mr. Fisher, and especially from central station men who have had experience with high-voltage cables. What is the highest voltage limit that we can now safely depend upon in cables?

MR. WALTER F. WELLS:—In reply to Mr. Mershon's question, I would say that it is the practice of the New York Company not to make over-voltage tests on cables; and this also applies generally speaking to all electrical apparatus. Apparatus as well as cables thoroughly tested before being installed. A test of a slight over-voltage, say 20 per cent. to 30 per cent., is enough to determine whether the work has been properly done or not.

As to the four faults referred to by Mr. Torchio, which might have been found by an over-voltage test originally, two of them were probably short bends in manholes. As to the other two, I am not well enough acquainted with the records to know which they were. They must have been some of the faults in splices.

Those shown by low insulation test evidently were good in the beginning and gradually deteriorated.

MR. MERSHON:—How about these faults designated as "in splice"?

MR. WELLS:—Those evidently were all right in the beginning and gradually deteriorated, whether due to external injury or not, I cannot say. Several companies operate in the same manholes, and sometimes the cables are roughly handled by employees of other companies or by contractors working on the Rapid Transit Subway excavations.

MR. STOTT:—In reference to the absence of tests on cables, I would say it is the practice of the company with which I am connected to make a 30 minute test of 100 per cent. over-voltage. That is to say, on the 11,000 volt cables which we operate, we would make a 30 minute test at 22,000 volts on the insulation between the three conductors and between the conductors and the ground. We find that a joint which is comparatively poor will stand up as long at 18 minutes and then break down, and in every case where we have broken down cables with the 30 minute test, the result has been fully justified by what we found in the joints. Incidentally, I can perhaps throw a little light on Mr. Mailloux's question as to the reliability of cables. We have in operation on 11,000 volts, three-phase, over 120 miles of underground cable. Out of that 120 miles we have had only one fault in the cable itself. All the rest were due to inferior work in the joints; and I would say that since they went into operation 20 months ago, we have had a total of four breakdowns while operating. All the rest were taken care of in the over-potential tests. Out of the entire 120 miles there has only been one spot of weak cable. I think that is a very remarkable record and one that shows that 11,000 volts is an absolutely safe voltage. We have the feeling that 11,000 volts is a great deal easier to handle underground than 650 on a grounded return circuit, because you are very liable to get a very large current coming back through the lead covering.

On the grounded system, such as we operate, no matter how much copper you put in to bring back the current to the negative bus-bar, it is almost a physical impossibility to get enough copper in the street to reduce the drop below, say, 10 volts. The lead sheet of a cable $2\frac{3}{8}$" diameter has a resistance of approximately 1/10 of an ohm per thousand feet, so that a length of 500 feet subjected to 10 volts will give you something like 200 amperes in the lead sheath. We found by actual test that the lead sheet of such a cable, $2\frac{3}{8}$" external diameter, and the sheath itself being 9/64th inches thick, would only stand 400 amperes continuously until it reaches 100° C. rise. That of course was too high. I think that a great deal of the underground trouble has been due, not to faults in the insulation but to faults in the lead sheath. That is to say, stray currents from other properties have got back into that lead sheath and melted off the lead in spots where it touches

the hanger in the man hole. Of course, that admits moisture, and the insulation gradually deteriorates and breaks down.

Incidentally, I do not think it is worth while considering or discussing rubber-insulated cables at the present time, because the cost of a rubber cable is approximately 100 per cent. greater than that of a paper cable.

We have installed reverse-current relays in our substation feeders, but owing, as I said, to the fall in potential affecting the shunt coils, we found them entirely unreliable. That is to say, in case of short circuit in one feeder, the other feeders will all go out together, owing to the overload current carried by them through the substation to the break in the cable; so that whenever one feeder went up it invariably meant that the entire substation was shut down for a period of from two to five minutes, according to the number of rotaries that were running. Again, there is always a doubt existing in the mind of the operator as to which one of the five or six feeders was in trouble, as all the circuit-breakers went out at the power house, and it was very difficult for them to tell, without testing, which one was in trouble. I do not know how Mr. Wells' people operate in that way, but we found it absolutely impossible to determine which feeder was in trouble, as all the overload breakers went out simultaneously. To get around that, we simply separate the feeders at the substation so that each feeder supplies its own rotary. We have had short circuits on feeders since that change was made and the automatic apparatus took care of it perfectly without any interruption whatever to the service at the power house or substation. In fact, no one knew anything about it until the indicating lamps showed that the oil-switch had gone out. I believe a new device has been gotten up by one of the manufacturing companies which is really not a reverse current relay, but a system they have of causing one relay to lock the others. Suppose there are three or four feeders in multiple—the one which has the short circuit on it will evidently receive the greater amount of current. Therefore its solenoid will move up faster than the others, which are merely carrying the overload. As that one reaches the limiting point it closes a contact which locks all the other feeder relays in that substation. As soon as it breaks it trips its own circuit-breaker; then it releases all the other relays again. It is simply a little solenoid at right angles to the core of the primary solenoid, and it drags over the core so hard that it cannot move vertically. That has been laid out and is going to be installed on the underground division of the Interborough Rapid Transit Company, but I do not think it has been put into actual use up to date.

MR. H. W. FISHER:—I will commence by answering Mr. Mershon's first question.

About two months ago I spent nearly five weeks with the Niagara Falls Power Company conducting experiments to determine the rise of temperature due to different currents on cables

laid in ducts. We experimented on different single conductor cables ranging from 3/0 to 1,250,000 c.m., and also on two and three conductor cables. The temperatures of the ducts at different points were determined by means of thermo-couples, consisting of rubber covered iron and German silver wires, all of which had previously been compared with a thermo-couple which we used as a kind of standard and the terminals of which we kept daily at the temperatures of ice and of boiling water. We also used resistance coils which had previously been calibrated to give the variation of resistance with temperature. Our experiments revealed the fact that there was a great deal of difference in the radiating power of different ducts; that the corner ducts radiate best, and the middle and top ducts become the hottest. Some tests made by the Niagara Falls Power Company revealed the fact that the top ducts were the hottest; an explanation of this is that there were openings here and there at points where the terra cotta ducts are joined together, through which the heated air circulated in an upward direction.

Tests of different numbers of 1,250,000 c. m. cables showed that the rise in temperature of the duct when four cables were employed was 85 per cent. of what it was when eight cables were employed; and when two cables were employed the rise was 74 per cent. of what it was for eight cables.

The Niagara Falls Power Company is in some cases using water circulation in iron pipes to reduce the temperature of the ducts, and by so doing a reduction of 20° Centigrade was obtained in one case.

MR. MERSHON:—What is the maximum temperature that a cable will stand continually without injury to the insulation?

MR. FISHER:—I can say that 100° Centigrade continually applied to a paper cable will eventually deteriorate the paper, making it quite brittle.

I am conducting experiments along this line now to find out the maximum temperature which will not injure paper-covered cables.

With reference to Mr. Mailloux's question as to whether cables sold for a certain voltage could not be subjected to twice that voltage when it is desirable to raise the voltage in the generator plant, I would say that it is hardly fair to subject cables to a working pressure much in excess of what they are designed for. Whether this could be done or not would depend largely on the kind of cable and the voltage at which it was normally designed to work.

MR. MAILLOUX:—What is the highest voltage you have made them for?

MR. FISHER:—Cables are working now at about 22,000 volts.

MR. MAILLOUX:—Are they to be obtained under guarantee for that amount?

MR. FISHER:—Yes. By experience and experiment we are continually learning improved methods of manufacture and dis-

covering better insulating compounds, and for some time at least I think we will be able to supply what is likely to be required in the line of high-voltage cables.

MR. MAILLOUX:—You say 22,000 volt cables are commercially obtainable to-day?

MR. FISHER:—Yes.

MR. MAILLOUX:—That is what I wanted to know.

[COMMUNICATED AFTER ADJOURNMENT BY MR. W. L. WATERS.]

ELECTRIC CABLES FOR HIGH-VOLTAGE SERVICE.

I think the question of rubber vs. paper for high-tension cables is a commercial rather than an engineering question. Paper cables are simpler to manufacture, and hence are usually more reliable in practice, but I think there is nothing to choose as regards reliability between well-made rubber and well-made paper cables, provided they are lead covered.

I used to be connected with a firm which has probably had more experience than any other in the manufacture of rubber insulated cables, and we found that the chief points for reliability in rubber cables were good vulcanizing and keeping the rubber from contact with the air. No amount of text-book science will teach a man how to vulcanize a cable; it is an operation that can only be learned by experience. And if the men making the cables have not had this experience, the cables turned out by any firm will in all probability not be very reliable.

The rubber on a cable which is poorly vulcanized becomes rotten after being in service for a certain length of time, and it cracks and crumbles, especially when subjected to mechanical stress. When rubber is exposed to the air for any length of time, the sulphur apparently works out to the surface and oxidizes, forming sulphuric acid. This effect is more pronounced when the insulation is under electric stress on account of the formation of ozone, and is also more marked in a cable which is poorly vulcanized. The result in any case is the same, that the cable breaks down sooner or later.

In rubber cables, as in most other questions regarding the permanence of insulation, the purchaser is more or less at the mercy of the manufacturer, and I think that the cable manufacturer should receive his due share of the credit for a number of the mysterious breakdowns that we hear of on high-tension rubber cables.

DISCUSSION ON "USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS."

MR. R. S. KELSCH:—A plant operated by the writer for five years, was equipped with expulsion type fuse blocks using aluminum fuses, on the eight 750 k.w. generators, and the same type of fuse on the eight 5000 volt transmission lines at both the receiving and the generating ends, and gave excellent results.

On one occasion the collector rings for the field leads of one of the generators short-circuited when the eight machines were operating in multiple. The disabled generator was dis-

connected from the system without the trouble being recorded on the recording voltmeter in the city substation.

On several occasions one or more of the lines were short-circuited by wire thrown on the transmission line, and on each occasion the disabled line was disconnected without interrupting the service. During the past year, relays have been employed and the fuses removed, and we have not had as good results.

Recently a dead short-circuit on one of the secondary circuits protected by a time-limit overload relay set for three seconds caused the potential of the system to fall so low that all power service was interrupted.

Reverse-current relays should be set to operate at five per cent. reverse current. Reverse current should not occur except under abnormal conditions and under these conditions, the apparatus protected by reverse-current relay, should be disconnected instantaneously, and should not have a time element attachment. A reverse-current relay so constructed would operate before the potential lowered sufficiently to make the relay inoperative. The only objection to setting a reverse-current relay to operate at five per cent. is the difficulty in synchronizing. This, however, can be obviated by synchronizing with the incoming generator pressure slightly above the bus pressure and the synchronizer indicating that the speed of the incoming generator is a trifle higher than the general system, which will insure the incoming machine acting as a generator the instant the switch is closed.

DR. F. A. C. PERRINE:—One question which has been touched on by a number of papers in this discussion, but which has not been specifically treated, is that of the proper subdivision of the lines for their protection from interference. The apparatus for line switching and line insulation has been treated for protection against lightning and the subdivision of the circuits has been considered, but it seems necessary to call attention to the fact that we have not, as yet, treated the question of dividing the line up into sections so that in case of accident the interference with the proper maintenance of supply by reason of the use of multiple lines shall not become excessive.

The importance of this was recently called to my attention by some calculations I have been making on a line 350 miles long, for which figures have been requested. If two lines were installed for this transmission, using such a size of copper as the question of economy would best warrant, the regulation, when only one of the two lines was in service, would be too bad for the proper supply of energy to the service. In consequence it was necessary to consider whether the size of line wire be increased or the line divided up in sections, which would permit cutting out only a short section in case of accident anywhere along the line.

In lines approaching 100 miles in length, the capital invested in each pole line is very considerable and in addition to the loss of energy which must be excessive if but one of the lines is in operation, there is a heavy capital charge during such times which must be carefully considered.

On most long-distance lines there are points of distribution along the line which naturally cut such a line up into sections and if switching stations are installed at these distribution points, permitting the transposition of the circuits, the effect desired can be accomplished but it is not always possible to rely on the fortuitous arrangement of switching stations. With increased length of line, there may be great distance between these switching stations, and furthermore the change-over switches operate under much more serious conditions when the sections they are controlling are long than when they are short.

It is true that up to the present time there has been a general tendency to avoid multiplying switching stations on account of the imperfection of high potential switching apparatus and the increased danger induced will be somewhat above the necessary imperfection of insulation in the switching apparatus itself. Such imperfection, however, is not a necessity and is one of the questions which must be solved in order to obtain satisfactory long-distance transmission. This problem solved, the multiplication of switching points is feasible and this implies that with long lines, where two or three duplicate transmission circuits are established, it will become necessary to establish switching substations for no other purpose than the cutting out of sections in the line when repairs become necessary, thus obtaining satisfactory regulation, the efficient employment of the large amount of chemical which is necessarily employed in the transmission for great distances.

Such switching stations have been proposed as frequently as ten miles apart. The ordinary practice is not to install them more frequently than fifty miles apart. It is the writer's opinion that they should not be more distant than twenty-five miles, and their location at fifteen or twenty mile points would be more practical. Handling circuits at this short distance will be easier on the switching apparatus itself. Where switching stations are installed fifty or seventy-five miles apart, the high capacity of the line between switching stations increases the difficulty of switching, but even at the highest voltages, transposition switches can be installed with comparative ease, provided only, as I have already said, their insulation be sufficient to prevent concern for the safety of the circuit from this cause.

In connection with this question comes in the important problem of the use of automatic switching apparatus for such switching, and while the writer believes that the use of automatic switching apparatus be very advisable, at the same time we must recognize that at the present time the main problem of switching has not been so satisfactorily solved as to permit our consideration of automatic apparatus, however desirable it may be.

PRESIDENT SCOTT:—We have had to-day, according to a little account I have been keeping here, something like 75 contributions to the discussions on the papers which have been presented. You

will notice that the papers which have been presented, eight in number, are all by recognized experts in their several lines of work, and the discussions are from equally well-known men. Our Committee on High-Tension Transmission is to be very highly congratulated on what they have given us, and the response they have obtained.

We are adjourned until half-past nine to-morrow morning

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF LIBRARY COMMITTEE.

We beg to submit herewith a report on the present condition of the Library of the INSTITUTE, including a statement of receipts and expenditures from the inception of the Library, to May 1, 1903; statistics as to the number of volumes and titles; valuation of books and fixtures; statement of sources from which the books have been derived, etc. Owing to the extraordinarily rapid manner in which the Library has sprung up, an immense amount of detail has been involved in establishing it on a firm basis with respect to records, collation of periodicals, cataloguing and other work necessary to place the collection in permanent order and efficient working condition, as well as to determine the additions immediately desirable of modern books and those necessary to fill out incomplete sets of periodicals and transactions of learned societies. This work is now so far advanced as to admit of the compilation of the statistics submitted herewith. As this is the first report which the Library Committee has rendered, it may not be amiss to place on record here a brief account of the inception and growth of the Library.

At a meeting of the Council in January, 1900, $500 was appropriated for the purchase of two book stacks and to defray the cost of binding the more important of the periodicals received in exchange for the INSTITUTE TRANSACTIONS, and which for years had been accumulating. At the same time a Library Committee was named to carry out this work. Previous to the appointment of the Committee the INSTITUTE had a miscellaneous collection of several hundred books, largely the gift of the late George B. Prescott, Jr., and of publishers, together with several bound sets of electrical periodicals. In January, 1901, the Committee asked

for another appropriation of $500, but receiving only $100, it was decided that an endeavor should be made to enlist the interest of individual members in building up the Library. Though no general appeal was made, the response from the beginning was extremely encouraging, and the result to date is indicated in the statement that of 8,139 volumes now in the Library, all but 1,653 are the gift of individual members, this latter number also including 395 volumes purchased from the Carnegie fund; aside from bound exchange periodicals, only 14 volumes have thus far been purchased from INSTITUTE funds. The list of donors to date includes 57 names.

The first gift received was a complete set of *Comptes Rendus* (140 volumes) from Mr. C. O. Mailloux, followed soon after by a set of the *Proceedings* of the Royal Society, from Mr. Edward Caldwell, and sets of the *American Journal of Science* and *Journal* of Franklin Institute, from Dr. Cary T. Hutchinson. During the first three months the gifts aggregated almost 500 volumes.

The latter part of February, 1901, it was learned that the celebrated Latimer Clark Collection of electrical books, pamphlets, autographs and portraits was for sale, and the matter of its purchase for the INSTITUTE was immediately brought to the attention of Mr. Andrew Carnegie. While the negotiations with Mr. Carnegie were proceeding, but yet in doubt, Dr. Wheeler purchased the collection, and signified his intention of presenting to the INSTITUTE the books and pamphlets contained therein. Subsequently, a favorable reply was received from Mr. Carnegie, and when a committee called to inform him of the circumstances under which the collection had just been bought, he expressed much admiration for the *esprit du corps* exhibited by Dr. Wheeler; and the suggestion having been made that a fund would be desirable with which to house, catalogue and complete the collection, he immediately said he would donate for that purpose a sum equal to the expenditure of Dr. Wheeler. When the total cost, $6,880.28, was finally determined and communicated to Mr. Carnegie, he gave his check for that amount. Of this sum $828.10 has been expended for book stacks and library fixtures, $3,500 was set aside for a bibliography of the collection, and the remainder was reserved for book purchases.

At the annual meeting, May 21, 1901, Dr. Wheeler presented to the INSTITUTE the books and pamphlets of the Latimer Clark collection, subject to certain conditions set forth in a Deed of Gift, as follows:

"*First.*—The library to be kept insured against loss by fire as fully as it may be practicable to determine its value, and an annual appropriation of $1,500 to be provided for its maintenance.

"*Second.*—A complete catalogue *raisonné* to be published in the name of the INSTITUTE, reciting the conditions of gift and explaining the features of interest of each book for the convenience and information of members. This catalogue to be prepared at once, and a bound copy of it to be placed in the hands of each member of the INSTITUTE.

"*Third.*—The library to be in charge and control of a library Board or Committee made up of members of the INSTITUTE, and not more than one-quarter of the whole number of members of this committee to be allied with any one commercial or other interest.

"*Fourth.*—The library to remain in New York City, and to be a reference library, free to all, including non-members, and available for consultation at least three days in the week, and some evenings and some Sundays as soon as the INSTITUTE is in permanent quarters.

"*Fifth.*—Rare books—that is, books which it is practically impossible to replace—to be exhibited under glass with suitable explanatory cards, and to be subject to closer examination only at the library, and upon suitable introduction of the visitor to the Library Committee, or their representative, the librarian, and under such other precautions as will positively assure the preservation and safety of the books.

"And further, it is my earnest desire that the INSTITUTE shall, within five years, raise a sufficient fund by subscription, and provide itself with a permanent home for its meetings and library, and that this home shall be centrally located, reasonably safe from fire and not heavily mortgaged. In case of the failure of the INSTITUTE to comply with the substance or spirit of these conditions, or with the desire expressed above for a permanent home, the library shall revert to me or my heirs or assigns"

For the information of members, a check list was printed in the INSTITUTE TRANSACTIONS of March, 1903, of the books and pamphlets in the Wheeler Gift published prior to 1826, including somewhat more than 900 titles. Dr. Wheeler has recently authorized the Library Committee to purchase at his cost such works as will make his gift as completely representative as possible of early electrical literature, and a list of such works is now being compiled.

The bibliography of the Wheeler gift is now under preparation at the hands of Brother Potamian, D. Sc. Lond., and Professor of Physics in Manhattan College, New York, a distinguished authority on early electrical literature. Each title will be accompanied by a note characterizing the contents of the volume, or indicating the feature that constitutes its value or celebrity. As the collection is particularly rich in the literature of early electrical science and in the pamphlet literature relating to the beginnings of the electrical arts, the work promises through its annotations to have a unique value aside from its character as a catalogue. The bibliography, which is at present more than half completed, will form a large octavo volume, and will probably issue from the press in the autumn of 1904. In accordance with the terms of the Wheeler Deed of Gift, a copy will be given without charge to each member of the INSTITUTE.

Next to the Wheeler gift in importance are the various donations by Mr. C. O. Mailloux, which are almost completely inclusive of the great TRANSACTIONS of French scientific bodies. In addition to the *Comptes Rendus* above referred to, the list includes complete sets of *Annales de Chimie et Physique* (317 volumes); *Journal de Physique* (29 volumes); *Mémoires de l'Académie des Sciences* from 1666 to date (250 volumes), lacking only the volumes for the years 1778–1795, which Mr. Mailloux has authorized the Library Committee to obtain at his cost when they come on the market; *Mémoires presentés à l'Académie des Sciences par Divers Savants* (34 volumes); *Proceedings* of the Austrian Society of Engineers (56 volumes); a complete set of *Zeitschrift für Instrumentenkunde* (25 volumes); and a number of early works relating to learned societies. Mr. Mailloux has also defrayed the cost of binding or rebinding several hundred volumes of his gift.

In order to keep up the several sets of his gift, Mr. Mailloux has presented to the Library a fund of such an amount that its annual proceeds will defray the cost of future subscriptions to the various publications and the cost of binding the yearly additions.

Mr. Edward D. Adams has donated a complete set in splendid condition of all the publications of the Royal Society. These include the *Transactions*, unabridged, from 1665 to date (223 volumes); *Proceedings* of the Royal Society (70 volumes); Royal Society "Catalogue of Scientific Papers," (12 volumes); and a complete set of the various histories of the Society—six in number, (10 volumes)—the total aggregating about 315 volumes. Mr. Adams defrayed the cost of rebinding the above uniformly

in half morocco with gilt tops, and is also having engraved at his cost by French, a book plate for the Library.

The American Bell Telephone Company presented a valuable collection (92 volumes) relating to the telephone, including Records, Briefs, etc., of telephone suits, and rare early publications and papers relating to the telephone; also 15 volumes of electric railway patent specifications from earliest issue to 1896.

Through the gift of five patent attorneys the Library has come into possession of a set of U. S. electrical patent specifications from the earliest up to June 30, 1891. This set is now being collated by classes preparatory to rebinding.

Mr. Joseph Wetzler presented a complete set of Dingler's *Polytechnisches Journal*, 1820–1901 (319 volumes), and from Mr Charles L. Clarke has been received a valuable collection of 40 volumes of Records, Briefs, etc., relating to incandescent lamp litigation.

Mr. B. J. Arnold has donated 5,000 marks for a complete set of *Annalen der Physik* from 1790 to date. As this includes all of the rare early volumes and all indexes and supplementary volumes, the set is probably the most complete in the United States.

From Mr. Thomas A. Edison a complete set of the valuable Italian periodical, *Nuovo Cimento*, has been received.

Following is a list of donors to May 1, 1903.

ADAMS, E. D.
AMER. BELL TEL. CO.
AMER. ELECTRICIAN CO.
ANDERSON, G. L.
ARNOLD, B. J.
AUERBACHER, L. J.
BOLTON, H. C.
BRITISH PATENT OFFICE.
BROWN, C. S. V.
BROWN, J. STANFORD.
BUCKINGHAM, C. L.
CAIRD, R.
CALDWELL, EDWARD.
CLARKE, C. L.
CONSERVATOIRE DES ARTS ET METIERS.
DE VINNE, T. L.
DUNOD, VVE.
DUNBAR, J. W.
DYER, R. N
ELECTRICAL REVIEW.
ELEC. WORLD AND ENG.
FISH, F. P.
GAUTHIER-VILLARS.
GRIFFIN, CHAS. & CO.
HOWSON & HOWSON.
HUTCHINSON, DR. CARY T.
JENKS, W. J.
JOHNSTON, W. J.
KEITH, DR. N. S.
KINSMAN, F. E.
LAWRENCE, W. J.
LOCKWOOD, T. D.
LOZIER, R. T. E.
MACMILLAN COMPANY.
MAILLOUX, C. O.
MCGRAW PUB. CO.
MARTIN, T. C.
NAT. ACAD. OF SCIENCE.
NAUD, C.

N. Y. ELECTRICAL SOCIETY.
OFFICE NAVAL INTELLIGENCE.
POPE, RALPH W.
REBER, COL. SAML.
ROSENBAUM, W. A.
SHELDON, PROF. SAML.
SOCIÉTÉ FRANCAISE DE PHYSIQUE
STIERINGER, L.
U. S. COAST AND GEODETIC SURVEY.
VAN NOSTRAND, D. C.
VARLEY, RICHARD
WAKEMAN, J. M.
WALDO, DR. LEONARD.
WEAVER, W. D.
WETZLER, JOSEPH.
WHEELER, DR. SCHUYLER S.
WILEY & SONS.
WOLCOTT, TOWNSEND.

All gifts received are acknowledged in the TRANSACTIONS of the INSTITUTE, the titles being accompanied, when thought advisable, by a note pointing out the scope of, or feature of interest in, a work. In case of gifts of Transactions, periodicals, etc., including a considerable number of volumes, the name of the donor is stamped on the back, thus giving to the collection an individuality and at the same time denoting the *esprit du corps* to which it owes its existence.

The policy of the Library Committee is to endeavor to make the collection so complete in all the original sources of electrical knowledge that it will be invaluable for purposes of historical and scientific research. To this end particular attention is at the present time being paid to obtaining sets of the transactions of the more important of the older learned bodies of the world, which up to about the middle of last century were almost the sole repositories of electrical knowledge. Owing to the demands of the libraries connected with technical courses, particularly those of the many technical schools now being organized in Europe, the rarity of these publications is rapidly becoming greater, and the indications are that in a few years the more important will be unobtainable.

So far as funds available will permit, there will be placed in the Library complete sets of the more important electrical periodicals which have been published during the past half century. About 60 of the leading current electrical and cognate periodicals are now bound annually. The greatest effort will be made to obtain for the Library copies of the records and briefs of all electrical American patent litigation, which are of extreme value with relation to the history of the art; and it is hoped eventually to place in the Library the electrical patent publications of the leading countries of the world. Finally, the plans include having the collection eventually contain every book and pamphlet that has been printed in this country relating to electricity.

To provide a complete working electrical library for engineers, lists as full as has been possible to compile have been made of all authoritative works in the English, French and German languages now in print and not in the Library, relating to electrical engineering and science. Recently several hundred volumes in the French and German languages have been placed on the shelves, these including the more important modern works in those languages. Part of an extensive list of English and American books has already been purchased, and during the year what funds are set aside for this purpose will be expended in further purchases. As received, a list of the books will be printed in the monthly TRANSACTIONS of the INSTITUTE.

The library is now housed in three rooms of the suite occupied by the INSTITUTE at 95 Liberty Street. The space is ill adapted for Library purposes and the room available for additions will probably all be taken up by the end of the current fiscal year. At present the books are being arranged on the shelves so far as possible in classes corresponding to the main divisions of electrical science and engineering. An author catalogue of the collection has been completed, but the matter of a subject catalogue has not yet been taken up. In view of the rapid rate at which the collection is growing, and the fact that those referring to the books with few exceptions do not need the same guidance as the patrons of the usual public library, the compilation of a subject catalogue can well be deferred until a later date.

The greatest need is an index to the various sets of scientific transactions and to the more important articles in the sets of the leading electrical periodicals. The Library Committee hopes at some time in the future to enlist the interest of some friend of the INSTITUTE in the matter of supplying this need by the donation of an endowment fund for the compilation and publication of keys to these classes. Some years would be required to compile and publish keys to the Transactions and periodicals, after which the proceeds of the endowment might be devoted to printing monthly an index to the periodical electrical and physical literature of the world, including papers read before the learned bodies of the world. While the plan of such publication has not yet been worked out in all of its details, the main feature is an index in which the entries would be as brief as consistent with their object in pointing out to a reader if the paper or article is one which would interest him, thus not having the character of

abstracts; and arrangements would be made with some book-selling firm or firms for the issue and sale of coupon books, and the issue of a list of all journals covered by the index, together with the prices at which copies would be supplied upon application.

Another extremely desirable addition to the Library is a complete set of U. S. Electrical Patent Specifications, and provision for keeping up the same, including binding. The beginning of such a collection has already been provided for through the generosity of the patent attorneys above referred to, and it is hoped to obtain from some friend of the INSTITUTE a sum sufficient to complete the collection and provide an endowment fund for its continuation in the future.

Your Committee has been ably seconded in the work of organizing the Library by Miss Josephine T. Bragg, the librarian, to whom the present efficient working condition of the collection is to be credited. With a thorough training as a librarian, Miss Bragg unites a professional zeal and quick intelligence that rapidly led to a practical familiarity with the collection which is of the greatest service to those who refer to it.

Following are given statistics of the Library under the heads of source, titles, volumes and valuation. The duplicates, which are all separately catalogued and carefully stored, furnish a nucleus for a branch of the Library which some time in the future may be considered. With this in view it is hoped in time to fill out the incomplete sets of periodicals comprised. In making up the valuation of the collection the following system was pursued:

The Wheeler Collection is valued at its cost, and where books were specially purchased for donation to the Library, the price paid for the same is entered. In the case of other books, the valuation is based on the wholesale price of books now in print, and on what it was thought the books out of print could be procured for if for sale at second hand. The newly bound volumes of periodicals were uniformly entered at $2.00 per volume, and those in older binding at this or a less price, depending upon the state of the binding. The donations consisting largely of patent records and specifications, such as those of the American Bell Telephone Company, and Messrs. Charles L. Clarke and Nathaniel S. Keith, have been given arbitrary values, which in each case is thought to be well within a price which a public library would be willing to pay for the several collections.

STATISTICS OF LIBRARY.

Source.		Titles.	Volumes.	Valuation.
OLD LIBRARY:				
Books		213	231	265.00
Periodicals		6	90	180.00
PURCHASES:				
Carnegie Fund		7	395	862.85
Institute Appropriations		14	14	33.22
Periodicals. Bound		72	923	1,846.00
S. S. WHEELER:				
Latimer Clark Collection	Books	1943	2048	6,880.28
	Pamphlets	3450	195	
	Periodicals	91	1378	
Recent Additions		62	74	120.25
GIFTS:				
E. D. Adams		9	315	2,019.06
American Bell Telephone Co		39	107	500.00
Chas. L. Clarke		8	40	100.00
Cary T. Hutchinson		88	371	643.94
Nathaniel S. Keith		43	55	100.00
C. O. Mailloux		12	850	1,803.23
McGraw Publishing Co		59	192	241.45
New York Electrical Society		51	54	52.50
W. D. Weaver		75	127	178.75
Joseph Wetzler		1	319	245.00
F. P. Fish, W. A. Rosenbaum, Howson & Howson, R. N. Dyer, C. L. Buckingham		1	97	500.00
Miscellaneous Gifts, (42 donors)		133	264	299.25
		6377	8139	16,870.78
Duplicates		178	412	659.68
Total		6199	7727	16,211.10

Following is the total valuation including permanent Library fixtures:

TOTAL VALUATION.

Books	$16,870.78
Book Stacks	1,100.25
Furniture, Catalogue Cases, etc	113.70
	$18,084.73

The following tables give the present state of the several Library Funds:

CARNEGIE FUND.

Dr.		Cr.	
Carnegie Donation.....	$6,880.28	Housings.....	$828.10
Interest to May 1, 1903.	212.87	Books.....	862.85
		Wheeler Bibliography...	538.10
		Unexpended.....	4,864.10
	$7,093.15		7,093.15

Of the unexpended balance of this fund, about $3,000 forms part of the fund set aside for the Wheeler bibliography; the remainder—about $1,800—will be expended in filling out incomplete sets of periodicals and transactions in the Wheeler gift, a list of which will shortly be placed with book-sellers, and for the purchase of certain sets of transactions of scientific bodies now lacking from the Library.

MAILLOUX ENDOWMENT FUND. ($1,000.)

No income has yet accrued from this fund.

As stated above, the proceeds of the Mailloux endowment fund are to be applied to keeping up the several sets of transactions and periodicals presented by Mr. Mailloux, including binding the same annually.

DONATIONS.

Dr.		Cr.	
Oct. 20. 1901.—Remainder Buffalo Entertainment Donations.....	$455.34		
Sept. 25, 1902.—C. O. Mailloux.....	1.028.23	Books (C. O. Mailloux)..	$1,271.03
Apr. 26, 1903.—C. O. Mailloux.....	350 00		
F. P. Fish.....	100.00		
W. A. Rosenbaum.....	100.00		
R. N. Dyer.....	100.00	Set Electrical Patents...	500.00
C. L. Buckingham.....	100.00		
Howson & Howson.....	100.00		
E. D. Adams.....	72.50		
		Unexpended	635.04
	$2,406.07		$2.406.07

The unexpended balance of the Donation fund will be applied to the purchase of modern books on electrical science and engineering, except where the donation was made for a specified purpose.

INSTITUTE APPROPRIATIONS.

Dr.		Cr.	
Jan. 24, 1900.—Appropriation	$500 00	Rent and Insurance	1,142.66
Jan. 9, 1902.—Appropriation	100.00	Salary and Labor	1,426.67
Annual Appropriation, May 1, 1901 to May 1, 1902	1,500.00	Furniture and Fixtures	620.00
Annual Appropriation, May 1, 1902 to May 1, 1903	2,500.00	Binding	752.60
Moving and Bookstacks,	370.00	Library Supplies	90.46
Carnegie Resolutions	57.40	Books	33.22
Printing in Transactions,	113.21	Express, cartage, postage	15.74
Printing, Library Dinner	7.25	Subscriptions	8.75
		Miscellaneous	26.70
		Moving	75.00
		Carnegie Resolutions	57.40
		Printing in Transactions,	113.21
		Unexpended	785.45
	$5,147.86		$5,147.86

The balance under this head consists principally of a balance from the fiscal year 1901–1902. The Wheeler Deed of Gift requires a minimum annual appropriation of $1,500, and as the Library expense did not commence until several months after the appropriation began, a balance remained at the end of the year. An error having occurred in charging on the books of the INSTITUTE several items to the Library, the Council made an appropriation to correct this, which accounts for the final four entries on the debit side.

ANNUAL APPROPRIATION, 1903–1904.

The annual appropriation asked of the INSTITUTE for Library purposes is limited to the sum required solely for the maintenance of the Library, and includes no provision for purchase of books or library fixtures, or for any other than routine expenses and binding The requirements for the fiscal year May 1, 1903, to May 1, 1904, will be as follows:

Rent	$1,505.04
Insurance	56.00
Salary, Librarian	780.00
Extra Assistance	50.00
Binding Periodicals, etc.	425.00
Library Supplies	125.00
Express, Postage, Miscellaneous	58.96
	$3,000.00

Respectfully submitted.

W. J. JENKS,
CHAS. E. KNOX,
LEONARD WALDO,
W. D. WEAVER, *Chairman*

NOTE:—Mr. Gano S. Dunn, remaining member of the Library Committee, was abroad when this report was prepared and presented to the Board of Directors.

ACCESSIONS TO THE LIBRARY.

The following is a continuation of the list of additions to the Library by purchase.

ADRESSBUCH der Elektricitäts-Branche und der damit Verwandten Geschäftszweige von Europa. 2 vols., 4°. Leipzig. 1900–1902.

ALBRECHT, G. Geschichte der Elektricität mit Berücksichtigung ihrer Anwendungen. xvi. + 336 pp., il., 8°. Wien. 1885.

ARNOLD, E. Konstruktionstafeln für den Dynamobau. 2 vols., F. Stuttgart. 1902.

AUERBACH, F. Die Wirkungsgesetze der Dynamo-Elektrischen Maschinen. xvi. + 250 pp., il., 8°. Wien. 1887.

BAUR, C. Die Entwicklung der Fernsprechkunst. 37 pp., 8°. Basel. 1886.

BENNDORF, H. Beiträge zur Kenntniss der Atmosphärischen Elektricität. II. Messungen des Potentialgefälles in Sibirien. 30 pp., pl., 8°. Wien. 1899.

BENNECKE, F. Untersuchung der Stationären Elektrischen Strömung in einer Unendlichen Ebene für den Fall, dass die Zuleitung der Beiden Verschiedenen Elektricitäten in zwei Parallelen Geradlinigen Strecken Erfolgt. 48 pp., pl., 4°. Halle. 1887.

BERICHT über die Internationale Elektrische Ausstellung Wien 1883. 577 pp., il., 8°. Wien. 1885.

BERICHT über die Verhandlungen der Hauptversammlungen des Internationalen Elektrotechniker-Congresses zu Frankfurt am Main vom 7 bis 12 September, 1891. xxxix. + 393 pp., il., 8°. Frankfurt am Main. 1892.

BERICHT der xiv. Kommission über den derselben zur Vorberathung überwiesenen Entwurf einer Fernsprechgebühren-Ordnung. 33 pp., 4°. Berlin. 1899.

BERICHT über die von der Wissenschaftlichen Commission der Internationalen Elektrischen Ausstellung Wien 1883, an Dynamomaschinen und Elektrischen Lampen Ausgeführten Messungen. xxi. + 224 pp., il., 8°. Wien. 1886.

BESCHREIBUNG der in der Reichs-Telegraphenverwaltung Gebräuchlichen Apparate, nebst einem Hefte Figurentafeln. 217 pp., + pl., Q. Berlin. 1899.

BOLTZMANN, L. Vorlesungen über Maxwells Theorie der Elektricität und des Lichtes. 2 pts., pl., 8°. Leipzig. 1891–1893.

BORCHERS, W. Entwicklung, Bau und Betrieb der Elektrischen Öfen zur Gewinnung von Metallen, Carbiden und Anderen Metallurgisch Wichtigen Produkten. 64 pp., il., 8°. Halle. 1897.

CAHEN, H. Die Berechnung Elektrischer Kraftverteilungsnetze für Gleich-und Wechselstromsysteme. 43 pp., 8°. Berlin. 1895.

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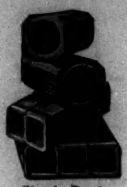

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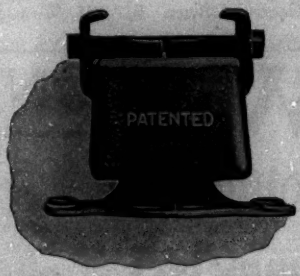

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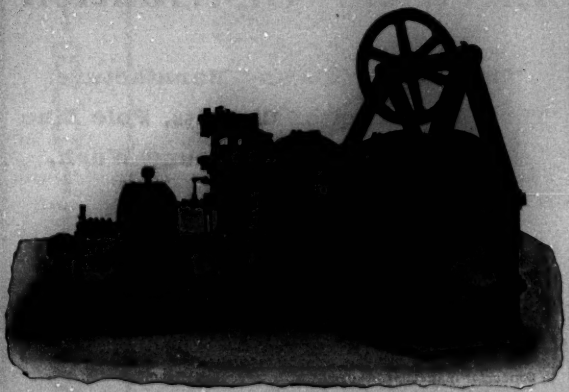

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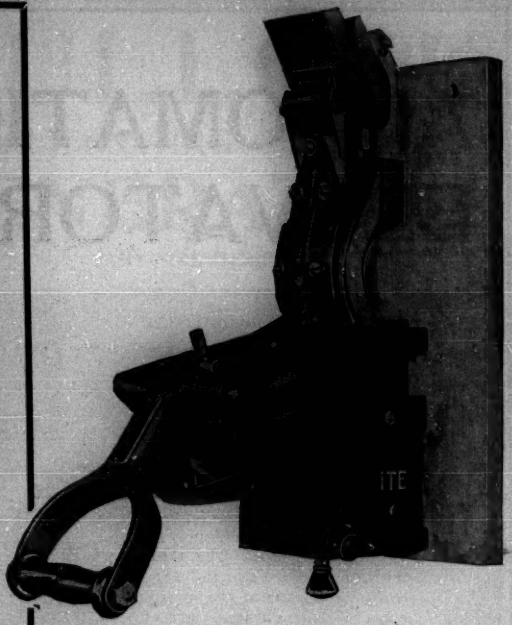

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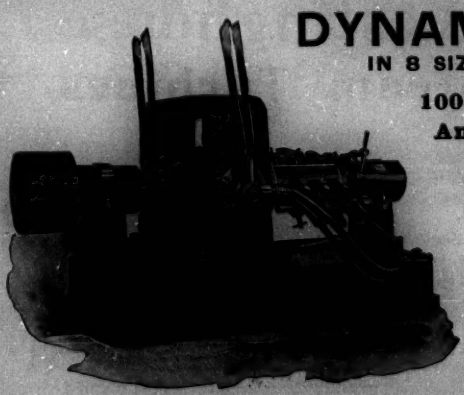

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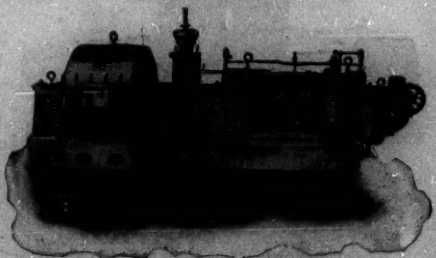

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